

A SYSTEM AND METHOD FOR DELIVERING AIR TO A SUBMERGED SHIP
SURFACE

FIELD OF THE INVENTION

[0001] The present invention relates broadly to methods of enhancing fuel efficiency for marine crafts, specifically, through use of hull air lubrication, and more particularly to an air delivery system for supplying air to a lower surface of a watercraft's hull.

BACKGROUND

[0002] As fuel costs fluctuate, technical leaders in the marine industry have directed watercraft design towards more energy efficient practices. Current technology implemented to solve this problem includes advanced hull shapes and designs, antifouling paints, and enhanced efficiency mechanical components. Typically, these technologies are not easily adapted for retrofit purposes. This makes it difficult to expedite fuel efficiency for the shipping industry.

[0003] One practice that has resulted from this more energy efficient shift is the theory of using air under a marine craft to provide a low frictional surface that reduces drag on the hull of the marine craft, known as hull air lubrication systems. However, current methods simply flood the area with air bubbles, many of which are wasted because they are too far away from the hull of the surface, and thus, the energy savings are often completely offset by the energy required to run the system. This leads to ship engineers turning the systems off because the use of these systems leads to more maintenance required without an efficiency benefit.

[0004] Air lubrication systems are still in a development stage. Current practices call for welding permanent nozzle grates directly into the steel hull of a ship, rendering improvements and/or modifications nearly impossible in water, outside of the 5 year drydock schedule.

[0005] Thus, a need exists in the industry for a carefully configured air delivery systems resulting in energy efficient air lubrication, with an efficient method of implementation, and configuration an air distribution system into the hull of a watercraft that results in net fuel efficiency. The present invention addresses the need for a method to economically install and test various air distribution nozzles to gain the maximum efficiency.

SUMMARY OF THE INVENTION

[0006] The invention disclosed herein provides air lubrication system nozzle assembly. The air lubrication system nozzle assembly includes a main body having an open cavity therein, wherein the main body includes a gas flow inlet, and an open lower boundary configured to receive a flow modulating nozzle flap. A flow modulating nozzle flap is provided. The flap is configured to modulate a direction and flow rate of a gaseous flow. The main body has at least one longitudinal engagement area, whereby the flow modulating nozzle flap may be coupled. A semi-circumferential flap mounting bracket forming an upper containment limit for the flow modulating nozzle flap is also provided. The air lubrication system nozzle assembly is operable in a submerged environment.

[0007] The invention disclosed herein also provides air lubrication system. The air lubrication system includes a superaerophilic inducing surface, a nozzle assembly, and an engaged air layer is created from the gaseous supply directed through the

nozzle assembly when pressurized. The superaerophilic inducing surface is mounted at an underside of a hull of a marine craft for use in reducing hydrodynamic drag on the hull of the marine craft. The superaerophilic inducing surface includes a functional surface, wherein the functional surface has a plurality of superaerophilic inducing microscopic and nanoscopic structures etched within the functional surface from laser ablation. Also, each superaerophilic inducing microscopic structure defines a trench and a ridge geometry. Each superaerophilic inducing nanoscopic structure defines a trench and a ridge geometry in a sidewall of each of the superaerophilic inducing microscopic structure.

[0008] The nozzle assembly is recessed into the hull of the marine craft and configured to disburse a gaseous supply over the superaerophilic inducing surface. The nozzle assembly of the system includes a main body having an open cavity therein, wherein the main body includes a gas flow inlet, and an open lower boundary, configured to receive a flow modulating nozzle flap. The flow modulating nozzle flap is provided, wherein the flap is configured to modulate a direction and flow rate of a gaseous flow. The main body has a semi-circumferential flap mounting bracket affixed at a border of the open lower boundary, wherein the mounting bracket provides at least one longitudinal engagement area, whereby the flow modulating nozzle flap may be hinged. The semi-circumferential flap mounting bracket forms an upper containment limit for the flow modulating nozzle flap. An engaged air layer is created from the gaseous supply directed through the nozzle assembly when pressurized.

[0009] The invention disclosed herein further provides a method for providing air to an underside of a marine craft's submerged hull. The method includes providing an air lubrication nozzle assembly capable of being immersed continuously in a liquid. The air lubrication system nozzle assembly includes a main body having an open

cavity therein, wherein the main body includes a gas flow inlet, and an open lower boundary configured to receive a flow modulating nozzle flap. The air lubrication system nozzle assembly also includes a flow modulating nozzle flap, wherein the flap is configured to modulate a direction and flow rate of a gaseous flow. The main body has at least one longitudinal engagement area, whereby the flow modulating nozzle flap may be coupled. The semi-circumferential flap mounting bracket forming an upper containment limit for the flow modulating nozzle flap. As such, the air lubrication system nozzle assembly is operable in a submerged environment.

[0010] It is an object of the present invention to provide a system that efficiently uses the principles of air lubrication to maximize the efficiency of the watercraft by reducing drag on the hull.

[0011] It is yet another object of the present invention to provide an air lubrication layer under a ship that can maintain its water repellant characteristics even during the movements normally associated with ships moving through both salt water and fresh water conditions, as well as calm and flowing water.

[0012] It is a further object to provide an air lubrication system capable of maintaining its efficiency between standard overhauls and drydock maintenance intervals, typically five years.

[0013] Another objective of the present invention is to recess a standardized air trunk into the hull of a ship, into which one or plural nozzle actuating devices can be installed and removed with relative ease.

[0014] The present invention describes an air distribution assembly with one or more component parts, one of which will allow for the installation, modification, removal and development of air distribution mechanisms that may be bolted directly into the receiver welded into the hull of a ship.

[0015] The drawings and specific descriptions of the drawings, as well as any specific or alternative embodiments discussed, are intended to be read in conjunction with the entirety of this disclosure. The invention may be embodied in many different forms and should not be construed as being limited to the embodiments set forth herein; rather, these embodiments are provided by way of illustration only and so that this disclosure will be thorough, complete, and fully convey understanding to those skilled in the art. The above and yet other objects and advantages of the present invention will become apparent from the hereinafter set forth Brief Description of the Drawings, Detailed Description of the Invention, and Claims appended herewith.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] **FIG. 1A** illustrates a bottom view of the main body of the nozzle system assembly.

[0017] **FIG. 1B** illustrates a bottom view of the nozzle system assembly showing the nozzle flap installed.

[0018] **FIG. 2** illustrates a top view of the nozzle system assembly.

[0019] **FIG. 3** illustrates a top perspective view of the nozzle system assembly.

[0020] **FIG. 4** illustrates a bottom perspective view of the main body of the nozzle system assembly.

[0021] **FIG. 5A** illustrates a bottom perspective view of the nozzle system assembly, showing the nozzle flap closed.

[0022] **FIG. 5B** illustrates a bottom perspective view of the nozzle system installed flush into the hull of a watercraft, with flap closed.

[0023] **FIG. 6A** illustrates a bottom perspective view of the nozzle system assembly, showing the nozzle flap open.

[0024] **FIG. 6B** illustrates a bottom perspective view of the nozzle system installed flush into the hull of a watercraft, with flap opened.

[0025] **FIG. 7A** illustrates a side view of the nozzle system with flap opened.

[0026] **FIG. 7B** illustrates a side view of a counterweight-type embodiment of the nozzle system, similar to that in **FIG. 7A**, with internal components shown in phantom.

[0027] **FIG. 7C** illustrates a cross-sectional side view of an embodiment of a reed-type embodiment of the nozzle system with flap opened and a screen mesh at an opening.

[0028] **FIG. 8A** illustrates a cross-sectional side view of the nozzle system assembly of the nozzle system, similar to that in **FIG. 7B**, with a counterweight-type flap.

[0029] **FIG. 8B** illustrates a cross-sectional side view of the nozzle system assembly of the nozzle system, similar to that in **FIG. 7B**, with a reed-type flap.

[0030] **FIG. 8C** illustrates a cross-sectional side view of the nozzle system assembly of the nozzle system, similar to that in **FIG. 7B**, with a spring-assisted reed-type flap.

[0031] **FIG. 9A** illustrates a conceptual view of a surface that is superhydrophilic when in air and superaerophobic when in water.

[0032] **FIG. 9B** illustrates a conceptual view of a surface that is hydrophilic when in air and aerophobic when in water.

[0033] **FIG. 9C** illustrates a conceptual view of a surface that is hydrophobic when in air and aerophilic when in water.

[0034] **FIG. 9D** illustrates a conceptual view of a surface that is superhydrophobic when in air and superaerophilic when in water

[0035] **FIG. 10A** illustrates an enlarged, not-to-scale, cross-sectional side view of the superaerophilic surface sitting in air.

[0036] **FIG. 10B** illustrates an enlarged, not-to-scale, cross-sectional side view of the superaerophilic surface sitting in water.

[0037] **FIG. 11A** illustrates a conceptual profile view of a ship using air lubrication with a superaerophilic surface covering part of its bottom.

[0038] **FIG. 11B** illustrates a conceptual plan view of a ship using air lubrication with a superaerophilic surface covering part of its bottom.

[0039] **FIG. 12A** illustrates a conceptual profile view of a ship using air lubrication with a superaerophilic surface covering part of its bottom.

[0040] **FIG. 12B** illustrates a conceptual profile view of a ship using an air lubrication system on an aerophobic hull.

[0041] **FIG. 13A** illustrates a conceptual cross-sectional side view of a nozzle system installed flush into the hull of a watercraft with open flap.

[0042] **FIG. 13B** illustrates a conceptual cross-sectional side view of a nozzle system installed flush into the hull of a watercraft with open flap, with a hull coated in a superaerophilic layer.

[0043] **FIG. 14** illustrates a system for carbon-enriched air lubrication delivery.

[0044] **FIG. 15** illustrates a flow chart of the carbon-enrichment process.

DETAILED DESCRIPTION OF THE INVENTION

[0045] The invention disclosed herein provides a system, method, and several apparatuses for delivering air through the hull of a ship onto the bottom portion of a ship hull through a carefully configured nozzle design, creating an air curtain which decreases the frictional drag of a ship as it moves through water. This invention offers increased performance of multiple factors influencing a vessel's efficiency while underway. The efficiency value is realized as lower fuel usage, less carbon emissions, simplified hull maintenance and ultimately lower operating costs.

[0046] As the fuel costs fluctuate, technical leaders in the marine industry have directed watercraft design towards more energy efficient practices. One practice that has resulted from this more energy efficient shift is the theory of use of air under a marine craft to provide a low frictional surface that reduces drag on the hull of the marine craft. However, current methods use open grates that simply flood the area with air bubbles, many of which are wasted because they are supplied as a deluge and the bubbles migrate too far away from the hull of the hull surface, and thus, the energy savings is often completely offset by the energy required to run the system. This leads to ship engineers turning the systems off because the use of these systems leads to more maintenance required without an efficiency benefit.

[0047] The invention herein provides a solution for these issues by incorporating a unique air distribution nozzle that minimizes water friction drag and controls the output of lubricating air based on the velocity of a ship with the invention installed. Distributing air to a hull surface immersed continually in a liquid is achieved by introducing an array of nozzles throughout a ship hull bottom surface. The nozzles have the ability to close automatically, and open when supplied with pressurized air. An air distribution system without a means to close the air distribution port will create

undue drag when a ship is underway, when not releasing the friction reducing air bubbles.

[0048] The nozzle system includes a nozzle assembly with a main body having a cavity for receiving an air supply from a feed pipe, whereby the air supply is diffused in the cavity uniformly, whereby the air supply flow approaches a closeable lower opening. A flap at the closeable lower opening modulates the flow of air out of the nozzle. Thus, the invention includes a configured recessed nozzle assembly having a flush flap capable of solving the above issues.

[0049] Another major issue that plagues current nozzle designs in the industry is the creation of oscillations during air delivery that mimic wave patterns. The Kelvin-Helmholtz instability properties, or the instability that can occur at the interface between two fluid layers of different densities and velocities when there is a velocity shear between them, can be a major problem for watercraft implementing air nozzles. This oscillation defeats the intention of keeping the supplied air close to a ship hull for maximum efficiency. The design of the nozzle, disclosed herein, reduces oscillation of the released air onto the hull of a ship because of the narrow gap between the nozzle flap and the upper boundary, whereby the disbursed air forms a thin film which does not create turbulence.

[0050] To achieve nozzle activation, one or more air compressors within a ship will supply pressurized air to the nozzle, opening one or more flap mechanisms affixed onto the nozzle assembly main body, and distributing the small air bubbles to the hull on the underside of a ship, creating what is known as an air plastron (the air between water and a ship hull surface). The nozzle also supports an engaged air layer under the hull once the air plastron is created, as long as the nozzle is pressurized.

[0051] For a wetted surface to move more efficiently in water, this air plastron (an air layer) can be used. The efficiency of the air delivery system is dependent on minimizing the amount of excess air bubbles created. Over supply of air bubbles equates to overuse of energy to create those bubbles. The air plastron acts as a slippery layer thus reducing the solid-liquid interface of the hull surface. As the solid-liquid interface decreases, the frictional adhesion of water to the hull surface drops causing reduced water drag.

[0052] In an underwater environment, the air plastron experiences a gradual reduction of volume due to external hydrostatic pressure and a convection-diffusion mechanism. This invention actively replenishes the air plastron by pneumatically supplying air to a ship's hull bottom through unique nozzles in the bottom of the hull surface, thereby sustaining the air plastron immersed in water. Air used to replenish the air plastron may also be enriched with carbon molecules to accelerate and enhance the creation of drag reduction properties.

[0053] My previous patent application, U.S. Serial Number 18/119,324, entitled "A System and Method for Reducing Drag on Hulls of Marine Crafts Thereby Increasing Fluid Dynamic Efficiencies", discloses creation of an air plastron using a constructed surface, which acts to attract air and repel water from the surface of the hull of a marine craft, all of which are incorporated in its entirety, herein.

[0054] For this implementation, one must appreciate the physics behind air plastron creation. Water is 50 times more dense than air. Up to 90% of the drag on a ship comes from friction on the hull due to water density. A layer of air between a ship hull and the water a ship moves through can decrease that drag by up to 70%. The main elements opposing the movement of a ship through water are bow pressure, hull friction and the wake created as a ship moves through water.

[0055] This invention herein discloses a way to actively supply air to the plastron with the goal of reducing water friction using the structures and principles disclosed herein. Millimeter sized air bubbles shall be pneumatically delivered through one or more of these nozzles from a supply of compressed air within a ship. The pressure of compressed air shall be greater than that of the hydrostatic pressure of the water pushing up against the bottom of a ship equipped with said invention. The volume of supplied air will vary with the conditions of travel, including but not limited to sea state, speed through the water and water temperature.

[0056] With respect to the effects of delivering air to the nozzles, as more air is delivered to the nozzles the pressure in them will increase and the movable flap will open to accommodate the increased pressure. The closer that pressure is to the opposing hydrostatic pressure, the slower the diffusion of air from the cavities will be. If the rate at which the air is delivered is equal or greater than the rate of diffusion, the air plastron will remain stable and be sustained over time.

[0057] The nozzle design opens only when lubricating air is desired, and stays closed when not in use, automatically adapting to the needs of a ship. When not in use, the unique nozzle design is flush to a ship's hull and will not cause additional friction loss as with other nozzle designs. In use, the nozzle is designed to adjust itself to the conditions of ship speed and air released through the nozzle.

[0058] In some embodiments, a compressor puts out enough force to create a 3-psi difference between the combined hydrodynamic forces and the spring force of the self-closing means acting upon a lower surface of the flap, and the force of air coming through the feed pipe pushing against the upper surface of the flap, which will create a narrow longitudinal gap for an optimum gaseous flow to escape. This psi may

be modified and independently configured for higher or lower psi to provide maximum efficiency for each application.

[0059] The nozzle includes a recessed portion, sometimes referred to as a sea chest or weldment. While sea chests are typically associated with receiving material, such as water with a seawater cooling circuit, the current sea chest defines a constructed cavern, or cavity, for diffusion of air or other gaseous output. This operation is more similar to what is commonly referred to as an air dispenser. However, the gaseous output in this application is forced through a linear nozzle opening. In some embodiments, the nozzle will be attached to an air accumulation tank to provide equal air delivery pressure across the width of the nozzle. An advantage of the use of a linear nozzle opening is the result in making the nozzle outlet aspect ratio wider than it is long, extending the distribution of bubbles along the axis of a ship. If an air accumulation tank is used, the air accumulation tank may incorporate internal air deflectors to distribute supplied air equally within the air accumulation tank. The overall body of the nozzle assembly includes multiple options for self-closing mechanisms for constricting the output size of the nozzle or closing the nozzle altogether.

[0060] The nozzle design includes a flap. The flap may be constructed of a semi-rigid material, which allows the flap to flex in some embodiments, but keep the flap substantially planar. Flaps may be constructed of metal, rubber, or both in some embodiments, to create a surface flush to a ship bottom and opening as required to become operational. Flaps may also be constructed of composites, resins, polymers, or the like. It is also to be appreciated that these materials allow the flap to return to its original positioning when not in use, without requiring mechanical actuation means.

[0061] Some of these mechanisms for self-closing the nozzle flap, by way of example and not limitation, include springs, vacuum pressure, and/or a counterweight which will close the nozzle in the absence of air pressure. Additionally, flaps may be fixed to the cavity, creating a reed valve, where the force of the air presses on the flap, thereby flexing an otherwise rigid surface. All of these embodiments involve creating a nozzle that becomes operational once air pressure is supplied to that nozzle. That is, the flap portion of the nozzle will return to non-operational position by use of counterweights, springs, or by use of other passive means including the tendency of the material used to resist bending and flexing.

[0062] An additional feature of this invention is its modifiable construction, which allows for development and upgrades to the flap mechanism without taking an equipped ship, out of the water, as is currently the case with other air lubrication system designs. As technology changes, more efficient designs may emerge. Permanently installed nozzles may become obsolete. The system disclosed herein allows for an exchange of air distributing nozzles within the recessed body, even though the recessed body may be permanently welded into a ship's hull.

[0063] The system and method of the present invention of delivering air to a constructed nozzle may be used to provide a system that efficiently uses the principles of air lubrication to maximize the efficiency of the watercraft by reducing drag on the hull. The present invention may be used to provide an air lubrication system capable of lasting for at least five years during the service life of a marine craft between overhauls and drydock maintenance. This system and apparatus, and thereby method, are particularly shown in **FIGS. 1A-14**.

[0064] **FIG. 1A** illustrates a bottom view of the main body **302** of the nozzle system assembly. As may be appreciated, the illustration also shows the nozzle cavity

304, gas flow inlet **306**, semi-circumferential mounting bracket **312** with longitudinal engagement area **316** at a forward area of complement **318**. **FIG. 1B** illustrates the same bottom view of the nozzle system assembly **300** showing the nozzle flap **310** installed.

[0065] **FIG. 2** illustrates a top view of the nozzle system assembly **300**, whereon the top of the gas flow inlet **306** can be seen. **FIG. 3** illustrates a top perspective view of the nozzle system assembly **300**.

[0066] **FIG. 4** illustrates a bottom perspective view of the main body **302** of the nozzle system assembly without a flap installed. As may be appreciated, the illustration also shows the nozzle cavity **304**, pipe coupling **306a** of the gas flow inlet, semi-circumferential mounting bracket **312** with longitudinal engagement area **316** at a forward area of complement **318**. **FIG. 5A** illustrates a similar bottom perspective view of the nozzle system assembly **300**, showing the nozzle flap **310** installed and closed. **FIG. 5B** illustrates a bottom perspective view of the nozzle system **300** installed flush into the hull **130** of a watercraft, with flap **310** closed. **FIG. 6A** illustrates a bottom perspective view of the nozzle system assembly **300**, showing the nozzle flap **310** open, thereby creating and demonstrating the longitudinal nozzle opening **336**, whereby the internal cavity **304** of the main body **302** can be seen. Also demonstrated is the forward area of complement **318**. **FIG. 6B** illustrates a bottom perspective view of the nozzle system **300** installed flush into the hull **130** of a watercraft, with flap **310** opened, hinged at the forward area **318**.

[0067] **FIG. 7A** illustrates a side view of the main body **302** of the nozzle system **300** with flap **310** opened. **FIG. 7B** illustrates a side view of a counterweight-type embodiment of the nozzle system **300**, similar to that in **FIG. 7A**, with internal components, including counterweight **326/326a** in open and closed positions, flap

310a in closed position, mounting bracket **312**, gas inlet **306**, and internal cavity **304**, shown in phantom. The flap **310** is shown open in non-phantom.

[0068] **FIG. 7C** illustrates a cross-sectional side view of an embodiment of a reed-type embodiment of the nozzle system **300** with flap **310** opened and a screen mesh diffusion panel **332** at an opening **308**. Also shown is the mounting bracket **312**, internal cavity **304**, and gas inlet **306**.

[0069] **FIG. 8A** illustrates a cross-sectional side view of the nozzle system assembly **300** of the nozzle system, similar to that in **FIG. 7B**, with a counterweight-type flap **310**. The counterweight **326** can be seen in both open position, with the closed position of the counterweight **326a** and flap **310a** shown in phantom. **FIG. 8B** illustrates a cross-sectional side view of the nozzle system assembly **300** of the nozzle system, similar to that in **FIG. 7B**, with a reed-type flap **310**. A characteristic of the reed-valve **322** construction is the mount without a means to return the flap to its original position, aside from its own internal elasticity. Positioning of the closed flap **310a** is shown in phantom. **FIG. 8C** illustrates another embodiment with the cross-sectional side view of the nozzle system assembly **300** of the nozzle system, similar to that in **FIG. 7B**, with a spring-assisted reed-type flap **322**. The spring **330** can be seen in a stretched state, which will contract when the flap **310** closes, as may be appreciated from the flap **310a** shown in phantom. Opening **308**, mounting bracket **312**, internal cavity **304**, and gas inlet **306** can also be seen in **FIGS. 8A-8C**. **FIGS. 7C-8C** further demonstrate the potential flex of the flap **310**.

[0070] **FIGS. 9A-9D** illustrate the concept of contact angle as it relates to the aerophilicity and hydrophobicity of a surface. **FIG. 9A** shows a surface that is superhydrophilic **102** when in air and superaerophobic when in water. In the top drawing, the contact angle of the water droplet on the surface surrounded by air is θ

$< 5^\circ$. In the bottom drawing, the contact angle of the air pocket on the same surface surrounded by water is $\theta > 150^\circ$. **FIG. 9B** shows a surface that is hydrophilic **104** when in air and aerophobic when in water. In the top drawing, the contact angle of the water droplet on the surface surrounded by air is $5^\circ < \theta < 90^\circ$. In the bottom drawing, the contact angle of the air pocket on the same surface surrounded by water is $90^\circ < \theta < 150^\circ$. **FIG. 9C** shows a surface that is hydrophobic **106** when in air and aerophilic when in water. In the top drawing, the contact angle of the water droplet on the surface surrounded by air is $90^\circ < \theta < 150^\circ$. In the bottom drawing, the contact angle of the air pocket on the same surface surrounded by water is $5^\circ < \theta < 90^\circ$. **FIG. 9D** shows a surface that is superhydrophobic **108** when in air and superaerophilic when in water. In the top drawing, the contact angle of the water droplet on the surface surrounded by air is $\theta > 150^\circ$. In the bottom drawing, the contact angle of the air pocket on the same surface surrounded by water is $\theta < 5^\circ$.

[0071] FIGS. 10A-10B illustrate a not-to-scale representation of the laser-ablated alloy's surface topography with structures created at the microscopic and nanoscopic scale, which creates a superaerophilic surface. **FIG. 10A** shows this surface sitting in air, while **FIG. 2B** shows this surface surrounded by water. As may be appreciated in **FIGS. 10A-10B**, shown are the microscopic-scaled ridges **110** left after creating laser ablated grooves, nanoscopic-scaled structures **112** induced by the laser, air **114** in which the embodiment shown in **FIG. 10A** sits, the created air plastron **116**, air bubble **118** that can penetrate the microscopic and nanoscopic-scaled surface and repel water, and water **120** in which the embodiment shown in **FIG. 10B** sits. The air plastron **116** shown in the figures also include an engaged air layer that engages above the micro-bubbles within the functional surface. In addition, further shown are water droplets **122** sitting on top of the surface surrounded by air. The water droplet

122 in this form has very little interface with the surface, minimizing the wetting of the surface. The air within the grooves helps keep the water from penetrating them.

[0072] **FIG. 11A** shows a profile view and a **FIG. 11B** shows a plan view of a ship using air lubrication with a superaerophilic surface covering part of its bottom. The air, after initially being injected, wants to remain attached to the superaerophilic surface of the hull. As may be appreciated in **FIGS. 11A-11B**, shown are the ship's hull **601**, the air bubbles **118** released at the air injection, the air **116** attached to the hull **130** over the area covered by the superaerophilic surface, and the surrounding water **120**.

[0073] **FIG. 12A** shows an air lubrication system used on a vessel with a superaerophilic surface, and **FIG. 12B** shows an air lubrication system on an aerophobic hull. As may be appreciated in **FIGS. 12A-12B**, shown are the ship's hull **130**, the air injection site **138**, the sustained air plastron **116** on the hull **130** with a superaerophilic surface, and air bubbles **118** bouncing off a hull using air lubrication over a traditional bottom.

[0074] **FIG. 13A** illustrates a conceptual cross-sectional side view of a nozzle **298** system installed flush into the hull **130** of a watercraft with open flap **310**. The gaseous flow **334** can be seen coming into the open cavity **304** of the main body **302** from the gas flow inlet **306**. This gaseous flow **334** pushes on the flap **310**, thereby creating a longitudinal opening **336** expelling the gas bubbles **118**. The bubbles **118** are seen accumulating under the marine craft's hull **130**. Similar to **FIG. 13A**, **FIG. 13B** illustrates a conceptual cross-sectional side view of a nozzle **298** system installed flush into the hull **130** of a watercraft with open flap **310**. However, **FIG. 13B** also shows the addition of a hull **130** coated in a superaerophilic inducing layer **340**.

[0075] **FIG. 14** illustrates a simplified system for carbon-enriched air lubrication delivery. As may be appreciated in **FIG. 14**, shown are the ship's hull **130**, the main engine **140**, the blackwater tanks/bioreactors **142a/142b**, the galley fume system **146**, the piping **148** that delivers carbon-enriched air to the Air Plastron Replenishment System, the carbon filter **150**, the gas injection site **152** for the carbon-enriched air being delivered to the Functional Surface Assembly's air plastron, a regular air compressor **144/176** for the ship's Air Lubrication System, the air injection site **138** for the air lubrication, and the created air sheet **116** on the ship's hull. Also shown is the air compressor **144**, which drives exhaust from the main engine and fumes from the blackwater tanks, bioreactors, and galley to the Air Plastron Replenishment System.

[0076] In some embodiments, the air distribution and replenishment system **234** is configured to receive a gaseous supply of carbon from at least one of an external atmosphere **246**, engine exhaust **156**, black water tank fumes **158a**, bioreactor exhaust **158b**, and galley hood fumes **158c**, whereby the gaseous supply is rerouted from the at least one of external atmosphere **246**, engine exhaust **156**, black water tank fumes **158a**, bioreactor exhaust **158b**, and galley hood fumes **158c** through a turbocharger **248** to a compressor input **174** in the compressor **144/176**, whereby the compressor **144/176** supplies the air distribution and replenishment system **234**.

[0077] **FIG. 15** illustrates a flow chart of the carbon-enrichment process. As may be appreciated in **FIG. 14**, shown are the engine exhaust gas **156**, and carbon-rich gases **158a/158b/158c** from other shipboard sources: the black water tanks, grey water tanks, and galley. Also shown is a combination of the gases **160** from the carbon-rich gases **158a/158b/158c** and the exhaust from the engine exhaust gas **156** that has been moved through a turbo compressor. Further shown is a carbon-enriched

air **162** that has passed through a carbon filter, and a carbon-enriched air **164** that is delivered to the bottom of the hull.

[0078] In an exemplary embodiment, air lubrication system nozzle assembly **300** is provided. The air lubrication system nozzle assembly **300** includes a main body **302** having an open cavity **304** therein, wherein the main body **302** includes a gas flow inlet **306**, and an open lower boundary **308** configured to receive a flow modulating nozzle flap **310**. The flow modulating nozzle flap **310** is also provided. The flap **310** is configured to modulate a direction and flow rate of a gaseous flow **334**. The main body **302** has at least one longitudinal engagement area **316**, whereby the flow modulating nozzle flap **310** may be coupled. A semi-circumferential flap mounting bracket **312** forming an upper containment limit **338** (see, for example, **FIG. 7C**) for the flow modulating nozzle flap **310** is also provided. The air lubrication system nozzle assembly **300** is operable in a submerged environment.

[0079] In some embodiments, the at least one longitudinal engagement area **316** is a semi-circumferential flap mounting bracket **312** affixed at a border of the open lower boundary **308**, as may be appreciated from the hinged flaps in **FIGS. 6A** and **6B**.

[0080] In some embodiments, the flow modulating nozzle flap **310** is coupled to the main body at the at least one longitudinal engagement area **316**. The at least one longitudinal engagement area **316** is positioned at a forward area **318** to direct flow of water under the flow modulating nozzle flap **310**, and provides a surface for hydrodynamic forces to press against to close the flow modulating nozzle flap **310** when no air is being dispensed from the opening **308/336** of the nozzle assembly **300**.

[0081] In some embodiments, the flow modulating nozzle flap **310** is removably coupled to the main body **302** by a pivot hinge **320** (as may be appreciated in **FIG.**

7B), allowing the hinge **320** to be uncoupled and the flap **310** to drop out when a change of flap technology is desired. In other embodiments, the flow modulating nozzle flap **310** may be coupled to the main body by affixing a mounting area **324** (as may be appreciated conceptually in **FIG. 7C**) on an upper surface **328** of the flap **310** to the at least one longitudinal engagement area **316**, whereby flexing of the flap **310** is accomplished by the functionality of a living hinge.

[0082] In some embodiments, the flow modulating nozzle flap **310** is configured to incorporate self-closing means **322/326/330**, whereby when not opened by the downward pressure of escaping gas, the flow modulating nozzle flap **310** is assisted to return to a closed state, as shown in **FIGS. 8A-8C**, and as may be appreciated by **FIGS. 5B** and **6B**. The self-closing means **322/326/330** may take several forms. In some embodiments, self-closing means of the flow modulating nozzle flap includes a reed valve closure **322**, with a mounting area **324** coupled to the semi-circumferential flap mounting bracket **312**. In other embodiments, the self-closing means may be a counterweight **326** affixed to an upper surface **328** of the flow modulating nozzle flap **310**, configured to pull the flow modulating nozzle flap **310** closed when tipping under its own weight, wherein the flow modulating nozzle flap **310** includes a mounting area **324** coupled to the semi-circumferential flap mounting bracket **312**. In further embodiments, the self-closing means of the flow modulating nozzle flap may include a spring-assisted **330** closure.

[0083] In some embodiments, the air lubrication system nozzle assembly **300** includes a diffuser panel **332** at the open lower boundary **308**, positioned above the flow modulating nozzle flap **310** and configured to a geometric shape of an outline of the open lower boundary **308**, whereby the diffuser panel **332** contains a plurality of through-holes **332a** to allow air to pass through, while influencing the size of air

particles passing through, thereby providing for smaller bubbles. The term “through-holes” is used in its broadest terms, and in some embodiments, the diffuser panel **332** may comprises a mesh material, though it should be appreciated that the diffuser **332** may be several other applicable materials, such as plastic with perforations, or materials incorporated after additional configuration. Such may include soapstone. However, the more difficult a material is to work with, the higher level of configuration and testing it will need to be sustainable as an embodiment. The overall purpose for the diffuser **332** is to separate the flow of gas into individual streams, thereby creating smaller bubbles, which have a greater chance of adhering to the constructed supraaerophilic inducing surface **340** to promote forming of an air plastron **116**, and thus, promotes the principles of air lubrication under the hull **310** of a ship.

[0084] In an exemplary embodiment, air lubrication system through-holes **332a** is provided. The air lubrication system **298a** includes a supraaerophilic inducing surface **340**, a nozzle assembly **300**, and an air plastron **116** created from the gaseous supply **334** directed through the nozzle assembly **300** when engaged. The supraaerophilic inducing surface **340** is mounted at an underside of a hull **130** of a marine craft for use in reducing hydrodynamic drag on the hull **130** of the marine craft. In some embodiments, the supraaerophilic inducing surface comprises a metallic surface, wherein the metallic surface has a plurality of supraaerophilic inducing microscopic **110** and nanoscopic **112** structures etched within the metallic surface from laser ablation. Also, each supraaerophilic inducing microscopic structure **110** defines a trench and a ridge geometry, as may be seen in **FIGS. 10A, and 10B**, and as may be appreciated from the disclosure of my earlier application, U.S. Patent Application Ser. No. 18/119,324, entitled “A System and Method for Reducing Drag on Hulls of Marine Crafts Thereby Increasing Fluid Dynamic Efficiencies”, incorporated

herein in its entirety. Each superaerophilic inducing nanoscopic structure **112** defines a trench and a ridge geometry in a sidewall of each of the superaerophilic inducing microscopic structure **110**.

[0085] The nozzle assembly **300** is recessed into the hull **130** of the marine craft and configured to disburse a gaseous supply **334** over the superaerophilic inducing surface **340**. The nozzle assembly **300** of the system includes a main body **302** having an open cavity **304** therein, wherein the main body **302** includes a gas flow inlet **306**, and an open lower boundary **308**, configured to receive a flow modulating nozzle flap **310**. The flow modulating nozzle flap **310** is provided, wherein the flap **310** is configured to modulate a direction and flow rate of a gaseous flow. The main body **302** has a semi-circumferential flap mounting bracket **312** affixed at a border **314** of the open lower boundary **308**, wherein the mounting bracket **312** provides at least one longitudinal engagement area **316**, whereby the flow modulating nozzle flap **310** may be hinged. The semi-circumferential flap mounting bracket **312** forms an upper containment limit **338** for the flow modulating nozzle flap **310**. An air plastron **116** is created from the gaseous supply directed through the nozzle assembly **300** when engaged.

[0086] In another exemplary embodiment of the air lubrication system **298a**, the system includes a superaerophilic inducing surface **340** mounted at an underside of a hull **130** of a marine craft for use in reducing hydrodynamic drag on said hull **130** of said marine craft, and a nozzle assembly **300** recessed into said hull **130** of said marine craft and configured to disburse a gaseous supply **334** over said superaerophilic inducing surface **340**. The superaerophilic inducing surface **340** comprises a functional surface **340a**, wherein the functional surface **340a** has a

plurality of superaerophilic inducing microscopic **110** and nanoscopic structures **112** constructed within said functional surface **340a** from imprinting the surface **340**.

[0087] In some embodiments, the functional surface **340a** is imprinted into a metallic material, in other embodiments, the functional surface **340a** is imprinted into a polymer material, and in yet further embodiments, the functional surface **340a** is imprinted onto a coating on a material. Imprinting of the nanoscopic **112** and microscopic structures **110** of the functional surface **340a** may be constructed by using laser ablation, drilling, punching, pressing, or a combination thereof into a subject material, typically a pre-altered piece of material, such as a polymer, metal, composite, or the like, of the functional surface **340a**.

[0088] In another exemplary embodiment, a method for providing air to an underside of a marine craft's submerged hull **130** is provided. The method includes providing an air lubrication nozzle assembly **300** capable of being immersed continuously in a liquid. The air lubrication system nozzle assembly **300** includes a main body **302** having an open cavity **304** therein, wherein the main body **304** includes a gas flow inlet **306**, and an open lower boundary **308** configured to receive a flow modulating nozzle flap **310**. The air lubrication system nozzle assembly **300** also includes a flow modulating nozzle flap **310**, wherein the flap **310** is configured to modulate a direction and flow rate of a gaseous flow **334**. The main body has at least one longitudinal engagement area **316**, whereby the flow modulating nozzle flap **310** may be coupled. The semi-circumferential flap mounting bracket **312** forms an upper containment limit **338** for the flow modulating nozzle flap **310**. As such, the air lubrication system nozzle assembly **300** is operable in a submerged environment.

[0089] In some embodiments, the method for providing air to an underside of a marine craft's submerged hull further comprises configuring portions of a ship's hull

130 for air delivery to a constructed superaerophilic surface **340** by providing at least one flush-installed linear nozzle **300**, wherein each of the at least one flush-installed linear nozzle **300** is the air lubrication nozzle assembly **300**. Each nozzle **300** in the at least one flush-installed linear nozzle is recessed up into the ship's hull **130**.

[0090] In some embodiments, the air lubrication nozzle assembly **300** is capable of performing the steps of passively lowering and raising the flow modulating nozzle flap **310**. Lowering the flow modulating nozzle flap **310** is achieved by using a flow of gas **334** received from the gas flow inlet **306** to lower the flow modulating nozzle flap **310**, wherein a flow of gas **334** disburses uniformly in the open cavity **304** of the main body, thereby pressing on the flow modulating nozzle flap **310** to allow air bubbles **118** to disburse to an underside of a marine craft's hull **130**, when air is required under the marine craft's hull **130**. Raising the flow modulating nozzle flap **310** is achieved by terminating a flow of gas received from the gas flow inlet **306**, whereby a passive lifting system is incorporated into the flow modulating nozzle flap **310** to allow for self-closure when the air is no longer required under the marine craft's hull **130**. It should be appreciated that the air compressor **144** must produce a pressure greater than the hydrodynamic pressure acting on the underside of the flap **310**, typically by at least a few psi.

[0091] Self-closing may be achieved by using one of several passive closing means **322/326/330**, or a combination and/or variations and/or equivalents thereof. Some embodiments may include configuring the passive lifting system incorporated into the flow modulating nozzle flap **310** to allow for self-closure when the air is no longer required under the marine craft's hull **130** by incorporating a reed valve closure **322**, with a mounting area **324** coupled to the semi-circumferential flap mounting bracket **312**. However, other embodiments may include configuring the passive lifting

system incorporated into the flow modulating nozzle flap **310** to allow for self-closure when the air is no longer required under the marine craft's hull **130** by incorporating a counterweight **326** affixed to an upper surface **328** of the flow modulating nozzle flap **310**, thereby configuring the counterweight **326** to pull the flow modulating nozzle flap **310** closed when tipping under its own weight, wherein the flow modulating nozzle flap **310** includes a mounting area **324** coupled to the semi-circumferential flap mounting bracket **312**. Lastly, some embodiments may include configuring the passive lifting system incorporated into the flow modulating nozzle flap **310** to allow for self-closure when the air is no longer required under the marine craft's hull **130** by incorporating a spring-assisted closure **330**.

[0092] In some embodiments of the method for providing air to an underside of a marine craft's submerged hull **130**, the method further comprises providing a diffuser panel **332**. This embodiment includes configuring the diffuser panel **332** to a geometric shape of an outline of the open lower boundary **314** to provide smaller bubbles to an underside of a marine craft hull **130**, whereby the diffuser panel **332** contains a plurality of through-holes **332a** to allow air to pass through, while influencing the size of air particles passing through. The embodiment of the method also includes positioning the diffuser panel **332** above the flow modulating nozzle flap **310** at the open lower boundary **308**.

[0093] While the preferred embodiment of the present invention has been described above, it is to be appreciated that the invention may be embodied otherwise than is herein specifically shown and described, and that certain changes may be made in the form and arrangement of the parts without departing from the underlying ideas or principles of this invention as set forth in the Claims appended herewith.

CLAIMS

1. An air lubrication system nozzle assembly, comprising:

a sea chest having an open cavity therein, wherein said sea chest includes a gas flow inlet, and an open lower boundary configured to receive a flow modulating nozzle flap;

a flow modulating nozzle flap, wherein said flap is configured to modulate a direction and flow rate of a gaseous flow;

said sea chest having at least one longitudinal engagement area, whereby said longitudinal engagement area is a rigidly fixed semi-circumferential bracket for mounting said flow modulating nozzle flap, wherein said rigidly fixed semi-circumferential bracket is affixed semi-circumferentially at a border of said open lower boundary;

said flow modulating nozzle flap is coupled to said at least one longitudinal engagement area; and

wherein said air lubrication system nozzle assembly is operable in a submerged environment.

2. The air lubrication system nozzle assembly, as recited in Claim 1, wherein said rigidly fixed semi-circumferential bracket forms an upper containment limit for said flow modulating nozzle flap.

3. The air lubrication system nozzle assembly, as recited in Claim 1, wherein said flow modulating nozzle flap is coupled to said sea chest at said at least one longitudinal engagement area, wherein said at least one longitudinal engagement area is positioned at a forward area to direct flow of water under the flow modulating nozzle

flap, and provide a surface for hydrodynamic forces to press against to close said flow modulating nozzle flap when no air is being dispensed from the opening of the nozzle assembly.

4. The air lubrication system nozzle assembly, as recited in Claim 1, wherein said flow modulating nozzle flap is removably coupled to said sea chest by a pivot hinge.

5. The air lubrication system nozzle assembly, as recited in Claim 1, wherein said flow modulating nozzle flap is coupled to said sea chest by affixing a mounting area on an upper surface of said flap to said at least one longitudinal engagement area.

6. The air lubrication system nozzle assembly, as recited in Claim 1, wherein said flow modulating nozzle flap is configured to incorporate self-closing means, whereby when not opened by the downward pressure of escaping gas, said flow modulating nozzle flap is assisted to return to a closed state.

7. The air lubrication system nozzle assembly, as recited in Claim 6, wherein said self-closing means of said flow modulating nozzle flap includes a reed valve closure, with a mounting area coupled to said rigidly fixed semi-circumferential bracket.

8. The air lubrication system nozzle assembly, as recited in Claim 6, wherein said self-closing means of said flow modulating nozzle flap is a counterweight affixed to an upper surface of said flow modulating nozzle flap, configured to pull said flow modulating nozzle flap closed when tipping under its own weight, wherein said flow

modulating nozzle flap includes a mounting area coupled to said fixed semi-circumferential bracket.

9. The air lubrication system nozzle assembly, as recited in Claim 6, wherein said self-closing means of said flow modulating nozzle flap includes a spring-assisted closure.

10. An air lubrication system nozzle assembly, comprising:

- a main body having an open cavity therein, wherein said main body includes a gas flow inlet, and an open lower boundary configured to receive a flow modulating nozzle flap;

- a flow modulating nozzle flap, wherein said flap is configured to modulate a direction and flow rate of a gaseous flow;

- said main body having at least one longitudinal engagement area, wherein said at least one longitudinal engagement area is a rigidly fixed semi-circumferential bracket for mounting said flow modulating nozzle flap, wherein said rigidly fixed semi-circumferential bracket is affixed semi-circumferentially at a border of said open lower boundary;

- said flow modulating nozzle flap is coupled to said at least one longitudinal engagement area;

- wherein said air lubrication system nozzle assembly is operable in a submerged environment; and

- a diffuser panel at said open lower boundary, positioned above said flow modulating nozzle flap and configured to a geometric shape of an outline of said open lower boundary, whereby said diffuser panel contains a plurality of through-holes to

allow air to pass through, while influencing the size of air particles passing through, thereby providing for smaller bubbles.

11. The air lubrication system nozzle assembly, as recited in Claim 10, wherein said diffuser panel comprises a mesh material.

12. An air lubrication system, comprising:

a superaerophilic inducing surface mounted at an underside of a hull of a marine craft for use in reducing hydrodynamic drag on said hull of said marine craft, comprising:

a functional surface; and

said functional surface having a plurality of superaerophilic inducing microscopic and nanoscopic structures constructed within said functional surface from imprinting the surface;

a nozzle assembly recessed into said hull of said marine craft and configured to disburse a gaseous supply over said superaerophilic inducing surface, wherein said nozzle assembly includes:

a main body having an open cavity therein, wherein said main body includes a gas flow inlet, and an open lower boundary, configured to receive a flow modulating nozzle flap;

a flow modulating nozzle flap, wherein said flap is configured to modulate a direction and flow rate of a gaseous flow;

said main body having a semi-circumferential flap mounting bracket affixed semi-circumferentially at a border of said open lower boundary, wherein said mounting bracket provides at least one longitudinal engagement area,

whereby said flow modulating nozzle flap is hinged to said at least one longitudinal area; and

said semi-circumferential flap mounting bracket forming an upper containment limit for said flow modulating nozzle flap; and

an engaged air layer created from said gaseous supply directed through said nozzle assembly when pressurized.

13. The air lubrication system, as recited in Claim 12, wherein each supraaerophilic inducing microscopic structure of said plurality of supraaerophilic inducing microscopic and nanoscopic structures of said functional surface defines a trench and a ridge geometry.

14. The air lubrication system, as recited in Claim 12, wherein each supraaerophilic inducing nanoscopic structure of said plurality of supraaerophilic inducing microscopic and nanoscopic structures defines a trench and a ridge geometry in a sidewall of each of said supraaerophilic inducing microscopic structure.

15. The air lubrication system, as recited in Claim 12, wherein the functional surface is imprinted into a metallic material.

16. The air lubrication system, as recited in Claim 12, wherein the functional surface is imprinted into a polymer material.

17. The air lubrication system, as recited in Claim 12, wherein the functional surface is imprinted onto a coating on a material.

18. The air lubrication system, as recited in Claim 12, wherein said imprinting of said nanoscopic and microscopic structures of the functional surface is constructed by using laser ablation, drilling, punching, pressing, or a combination thereof into a subject material of the functional surface.

19. A method for providing air to an underside of a marine craft's submerged hull, comprising:

configuring portions of the ship's hull for air delivery to said ship's hull's lower surface by providing at least one flush-installed linear nozzle, wherein each of said at least one flush-installed linear nozzle is an air lubrication nozzle assembly;

providing said an air lubrication nozzle assembly, wherein said air lubrication nozzle assembly is capable of being immersed continuously in a liquid, wherein said air lubrication system nozzle assembly includes:

a main body having an open cavity therein, wherein said main body includes a gas flow inlet, and an open lower boundary configured to receive a flow modulating nozzle flap, wherein said open lower boundary is flush with a transverse horizontal plane of a submerged hull of a ship surrounding said open lower boundary;

a flow modulating nozzle flap movably coupled to the open lower boundary of the main body, wherein said flap is configured to modulate a direction and flow rate of a gaseous flow;

said main body having at least one longitudinal engagement area, whereby said flow modulating nozzle flap is coupled to said longitudinal engagement area;

wherein said air lubrication system nozzle assembly is operable in a submerged environment; and

wherein the main body of each nozzle in said at least one flush-installed linear nozzle is recessed up into the ship's hull.

20. The method for providing air to an underside of a marine craft's submerged hull, as recited in Claim 19, wherein said air lubrication system nozzle assembly in said step of providing said air lubrication nozzle assembly capable of being immersed continuously in a liquid, further includes a semi-circumferential bracket for mounting said flow modulating nozzle flap, forming an upper containment limit for said flow modulating nozzle flap.

21. The method for providing air to an underside of a marine craft's submerged hull, as recited in Claim 19, further comprising:

configuring portions of said ship's hull with a constructed superaerophilic surface.

22. The method for providing air to an underside of a marine craft's submerged hull as recited in Claim 19, wherein the air lubrication nozzle assembly is capable of performing the steps of:

lowering said flow modulating nozzle flap by using a flow of gas received from said gas flow inlet to lower said flow modulating nozzle flap, wherein a flow of gas disburses uniformly in the open cavity of the main body, thereby pressing on said flow modulating nozzle flap to allow air bubbles to disburse to an underside of a marine craft's hull, when air is required under said marine craft's hull; and

raising said flow modulating nozzle flap by terminating a flow of gas received from said gas flow inlet, whereby a passive lifting system is incorporated into the flow modulating nozzle flap to allow for self-closure when said air is no longer required under said marine craft's hull.

23. The method for providing air to an underside of a marine craft's submerged hull as recited in Claim 22, further comprising:

configuring said passive lifting system incorporated into the flow modulating nozzle flap to allow for self-closure when said air is no longer required under said marine craft's hull by incorporating a reed valve closure, with a mounting area coupled to a fixed semi-circumferential bracket.

24. The method for providing air to an underside of a marine craft's submerged hull as recited in Claim 22, further comprising:

configuring said passive lifting system incorporated into the flow modulating nozzle flap to allow for self-closure when said air is no longer required under said marine craft's hull by incorporating a counterweight affixed to an upper surface of said flow modulating nozzle flap, thereby configuring said counterweight to pull said flow modulating nozzle flap closed when tipping under its own weight, wherein said flow modulating nozzle flap includes a mounting area coupled to a fixed semi-circumferential bracket.

25. The method for providing air to an underside of a marine craft's submerged hull as recited in Claim 22, further comprising:

configuring said passive lifting system incorporated into the flow modulating nozzle flap to allow for self-closure when said air is no longer required under said marine craft's hull by incorporating a spring-assisted closure.

26. The method for providing air to an underside of a marine craft's submerged hull as recited in Claim 19, further comprising:

providing a diffuser panel;

configuring said diffuser panel to a geometric shape of an outline of said open lower boundary to provide smaller bubbles to an underside of a marine craft, whereby said diffuser panel contains a plurality of through-holes to allow air to pass through, while influencing the size of air particles passing through; and

positioning said diffuser panel above said flow modulating nozzle flap at said open lower boundary.