

SYSTEM AND METHOD FOR ENHANCED MARINE VESSEL EFFICIENCY USING
INTEGRATED HULL OPTIMIZATIONS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation-in-part of U.S. Patent Application No. 18/948,969, filed November 15, 2024, which is a continuation-in-part of co-pending U.S. Patent Application Ser. No. 18/219,375, entitled "A System And Method For Delivering Air To A Submerged Ship Surface", filed July 07, 2023, and claims priority pursuant to 35 U.S.C. § 119(e) to U.S. Provisional Application Ser. No. 63/599,360, entitled "A Drag-Reducing Bow Thruster Cover For Maritime Vessels", filed November 15, 2023. U.S. Patent Application Ser. No. 18/219,375 is a continuation-in-part of 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", filed March 09, 2023, now U.S. Patent No. 12,097,932, which claims the benefit of priority pursuant to 35 U.S.C. § 119(e) to U.S. Provisional Patent Application Ser. No. 63/439,306, filed January 17, 2023, and U.S. Provisional Patent Application Ser. No. 63/427,144, filed November 22, 2022. U.S. Patent Application Ser. No. 18/219,375 also claims priority pursuant to 35 U.S.C. § 119(e) to U.S. Provisional Application Ser. No. 63/454,549, entitled "A System and Method for Delivering Air to a Submerged Ship Surface", filed March 24, 2023. All of which are hereby incorporated by reference in their entireties for all purposes.

FIELD OF THE INVENTION

[0002] The present invention relates to components used to reduce the drag on a hull of a marine craft, including air lubrication systems, bow thruster covers, and automated control systems.

BACKGROUND

[0003] As fuel costs fluctuate, the marine industry is beginning to adapt to more energy efficient practices. Current technology implemented to solve this problem includes advanced hull shapes and designs, antifouling paints, and enhanced efficiency mechanical components.

[0004] 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.

[0005] To produce a viable air lubrication system, the system must be able to account for various sources of drag. 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" focuses on a superaerophilic bottom hull surface to maintain an air plastron by encouraging air to adhere to the surface. That disclosure also introduces the air distribution system from compressors to the surface. U.S. Patent Application Ser. No. 18/219,375, entitled "A System and Method for Delivering Air to a Submerged Ship Surface" introduces a nozzle system to take air from the air distribution system and disburse it strategically below the hull of a ship, which is more readily

deployable than having a porous layer as described in the previous application. However, the embodiments in these applications alone can be enhanced with further contemplation.

[0006] Bow thrusters are auxiliary propulsion devices installed in the bow of maritime vessels, enabling better maneuverability at low speeds or when docking. These devices are particularly crucial for large vessels, such as cargo ships and cruise liners, where precise control is essential during harbor operations. Bow thrusters function by allowing water to flow through a transverse tunnel at the bow, generating lateral thrust.

[0007] However, the presence of the bow thruster tunnel introduces significant issues – increased hydrodynamic drag and creation of turbulent water prior to reaching an air lubrication nozzle. The drag occurs due to the disruption in the smooth flow of water along the vessel's hull, caused by the open tunnel. The consequence of this drag is a decrease in the vessel's overall efficiency, leading to higher fuel consumption and, consequently, increased operational costs and environmental impact. However, this also creates an issue for air lubrication nozzles, as the water becomes turbulent, affecting the efficiency of the system and the creation of a thin layer of air.

[0008] The efficiency loss is particularly noticeable in long-distance voyages where vessels operate at higher speeds and for prolonged periods. At these speeds, even a small increase in drag can lead to substantial fuel wastage.

[0009] In light of this, there has been a growing need for a mechanism to mitigate the drag caused by bow thruster tunnels. The proposed solution is a closable bow thruster cover – a device designed to streamline the hull when the bow thruster is not in use. By covering the tunnel, the vessel's hydrodynamic profile is significantly improved, leading to reduced drag and more efficient fuel usage. The covers disclosed herein also reduce turbulence associated with transverse tunnels, thereby providing a stable flow of

water, to the air lubrication system nozzles. The system disclosed herein also provides an additional solution of distributing air at the bow of a ship at the location of the pre-existing cavities for bow thruster covers, which in turn reduce drag at the furthest-most point of a ship.

[0010] Thus, a need exists in the market for a bow thruster cover, capable of maintaining a smooth and consistent hull surface is needed to reduce unnecessary drag and turbulence on the maritime vessel's hull.

[0011] Additionally, with the multiplicity of components of the system described herein, an additional component is increasingly necessary: an automated control system. While current air lubrication systems can be turned on and off by the user, it is not efficient in varying sea states where the hull is not perfectly flat. In such situations, air will dissipate towards the side it can rise fastest, leading to large swaths of areas of the ship hull which are then subjected to drag once again. In order for actual efficiency, an intelligent air lubrication system capable of monitoring sea states as a product of real-time feedback and adjusting the system based on the data is needed to optimize air outflow and flap/cover closure is imperative to continued savings in real-world conditions.

SUMMARY OF THE INVENTION

[0012] The invention disclosed herein provides a drag-reducing marine craft hatch. The drag-reducing marine craft hatch comprises a moveable transverse tunnel cover having an external submerged surface. The external submerged surface has a plurality of supraaerophilic inducing microscopic and nanoscopic structures imprinted within the external submerged surface, forming a supraaerophilic inducing surface. Each

superaerophilic inducing microscopic structure defines a trench and a ridge geometry, wherein each ridge structure defines a protruding structure.

[0013] The invention disclosed herein further provides a hydrodynamically optimized submerged surface of a marine craft. The hydrodynamically optimized submerged surface of a marine craft includes at least one moveable transverse tunnel cover and an air lubrication nozzle assembly. These surfaces for a substantially flush closure when not in use to avoid hydrodynamic drag. The air lubrication nozzle assembly includes a main body having an open cavity therein, and a flow modulating nozzle flap coupled to at least one longitudinal engagement area. The air lubrication nozzle assembly is operable in a submerged environment. The main body of the air lubrication nozzle assembly includes a gas flow inlet, and an open lower boundary configured to receive a flow modulating nozzle flap. The flap of the air lubrication nozzle assembly is configured to modulate and balance a direction and flow rate of a gaseous flow. The embodiment also creates an engaged air layer created from an air supply of the gaseous.

[0014] The invention disclosed herein yet further provides a method for increasing efficiency of a watercraft by reducing drag. The method includes configuring portions of a ship's hull for air delivery to the ship hull's lower surface by providing at least one air delivery nozzle. Each of air delivery nozzle is an air lubrication nozzle assembly. The method includes providing the air lubrication nozzle assembly. The air lubrication nozzle assembly is capable of being immersed continuously in a liquid. The air lubrication nozzle assembly includes a main body having an open cavity therein, wherein the main body includes a gas flow inlet, and an open air-interface boundary is disposed at a lower horizontal plane of a submerged hull of a ship surrounding the air-interface boundary. The air lubrication nozzle assembly is operable in a submerged environment. The method

further includes providing a stratified flow of water to the open interface boundary disposed at the lower horizontal plane by providing a pair of transverse tunnel covers at distal openings of a submerged transverse tunnel for each submerged transverse tunnel at a bow of the ship. the water flows over the exposed surface of each transverse tunnel cover, thereby reducing turbulence and hydrodynamic drag caused by non-hydrodynamically optimized surfaces. Each moveable transverse tunnel cover is disposed at a submerged substantially vertical plane.

[0015] The invention disclosed herein also provides an active system for reducing hydrodynamic drag on a hull of a marine craft, is disclosed. The system comprises an automated air distribution system. The automated air distribution system includes at least one compressor with a distributed automation-control module, at least one airflow modulation valves, and at least one air lubrication nozzle. The automated air distribution system couples one or more compressors to an automated valve with a plurality of air conduits. The automated air distribution system couples each automated valve to at least one air lubrication nozzles with at least one air conduit. Each automated valve includes a distributed automation-control module. The system also includes at least one moveable transverse tunnel cover with an external submerged surface. Each moveable transverse tunnel cover includes a controllable actuator, a user interface module, and a central automation-control module electronically coupled to at least each distributed automation-control module on each compressor, each distributed automation-control module at each automated valve, each controllable actuator, and coupled to the user interface module.

[0016] It is an object of the present invention to provide a system for reducing hydrodynamic drag on marine vessels through integrated hull optimizations including automated air lubrication control and dynamically adjustable hull features.

[0017] It is yet another object of the present invention is to provide a It is yet another object of the present invention to provide a bow thruster cover assembly that reduces turbulence and enables strategic air distribution at the forward sections of a marine vessel while maintaining operational functionality of the bow thruster.

[0018] It is a further object to provide a It is a further object to provide an intelligent control system that optimizes air distribution and hull feature positions based on real-time sea state conditions and computational fluid dynamic analysis to maintain maximum efficiency during vessel operation.

[0019] 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

[0020] **FIG. 1** illustrates a cross-sectional side view of the system shown in a marine vessel.

[0021] **FIG. 2** illustrates a diagram view of the system.

[0022] **FIG. 3** illustrates a partial bottom view of the bow of a hull of the marine vessel showing a nozzle layout and bow thruster covers.

[0023] FIG. 4A illustrates a side view of a nozzle of the system disbursing air under the hull of the ship.

[0024] FIG. 4B illustrates a side view of a nozzle of the system disbursing air under the hull of the ship having a superaerophilic coating.

[0025] FIG. 5 illustrates an isometric bottom view of a nozzle of the air lubrication system in an opened position.

[0026] FIG. 6 illustrates an isometric bottom view of a marine vessel hull with a recessed nozzle of the air lubrication system in an opened position.

[0027] FIG. 7 illustrates an isometric bottom view of a nozzle of the air lubrication system in a closed position.

[0028] FIG. 8 illustrates an isometric bottom view of a marine vessel hull with a recessed nozzle of the air lubrication system in a closed position.

[0029] FIG. 9 illustrates a front cross-sectional view of a transverse tunnel and a bow thruster.

[0030] FIG. 10 illustrates a front cross-sectional view of end sections of the transverse tunnel with distal bow thruster covers.

[0031] FIG. 11A illustrates a side view of a louvred-style transverse tunnel cover in an open state.

[0032] FIG. 11B illustrates a side view of a louvred-style transverse tunnel cover in a closed state.

[0033] FIG. 12A illustrates a side view of the components of a louvred-style transverse tunnel cover in an open state.

[0034] FIG. 12B illustrates a side view of the components of a louvred-style transverse tunnel cover in a closed state.

[0035] FIG. 13A illustrates a side view of a pivot-style transverse tunnel cover in a closed state.

[0036] FIG. 13B illustrates a side view of a pivot-style transverse tunnel cover in an open state.

[0037] FIG. 14A illustrates a side view of the components of a pivot-style transverse tunnel cover in a closed state.

[0038] FIG. 14B illustrates a side view of the components of a pivot-style transverse tunnel cover in an open state.

[0039] FIG. 15A illustrates an enlarged isometric view of a pivot-style transverse tunnel cover in a partially open state to expose air distribution channels.

[0040] FIG. 15B illustrates an enlarged isometric view of a louvred-style transverse tunnel cover in a partially open state to expose air distribution channels.

[0041] FIG. 16 illustrates a side view of multiple louvred-style transverse tunnel covers in a closed state with an air jet forward of the covers distributing air across the external surfaces.

[0042] FIG. 17A illustrates a front cross-sectional view of a transverse tunnel cover in a closed state.

[0043] FIG. 17B illustrates an enlarged front cross-sectional view of a transverse tunnel cover in a closed state showing the external surface in a superaerophilic texture.

[0044] FIG. 18A illustrates a partial flow chart of a method for increasing efficiency of a watercraft by reducing drag.

[0045] FIG. 18B illustrates a partial flow chart of a method for increasing efficiency of a watercraft by reducing drag.

[0046] **FIG. 18C** illustrates a partial flow chart of a method for increasing efficiency of a watercraft by reducing drag.

[0047] **FIG. 19** illustrates a flow chart for a method of lowering and raising a nozzle flap.

[0048] **FIG. 20** illustrates a flow chart for a method of expanding or constricting airflow to the air lubrication nozzles to actuate the opening or closing of each nozzle.

[0049] **FIG. 21** illustrates a flow chart for method steps of a program for an automated control module of an active system for reducing hydrodynamic drag on a hull of a marine craft.

DETAILED DESCRIPTION OF THE INVENTION

[0050] The invention herein provides a solution for reducing marine vessel energy inefficiencies caused by hull drag, turbulent water flow from bow thruster tunnels, and inconsistent air lubrication distribution in varying sea conditions. The invention includes a uniquely configured system of automated bow thruster covers integrated with an intelligent air lubrication system capable of solving the pre-stated issues.

[0051] Current marine vessel efficiency solutions rely on disconnected approaches, basic hull designs, and simple air bubble systems. These independent solutions operate in isolation, without considering their impact on each other or their combined effect on vessel performance. The result is suboptimal efficiency gains that often fall short of theoretical expectations.

[0052] Furthermore, existing air lubrication systems waste energy by flooding areas with excess air bubbles, while unprotected bow thruster tunnels create persistent turbulence that disrupts smooth water flow. These issues are exacerbated by the lack of intelligent control systems, leading ship engineers to frequently disable efficiency systems due to their poor performance in real-world conditions and increased maintenance requirements.

[0053] The current invention solves these problems by introducing an integrated approach that combines adaptive bow thruster covers with strategic air distribution points and intelligent control systems. This solution creates a synergistic effect where the bow thruster covers not only reduce drag but also condition water flow to enhance air lubrication effectiveness, while real-time computational analysis continuously optimizes

the entire system's performance based on actual operating conditions. The integration of these components, coupled with automated control and real-time adaptation, represents a significant advancement in marine vessel efficiency technology.

[0054] The invention herein provides a solution for several 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 when airflow is cut to the nozzle by utilizing the hydrodynamic forces of the water which the ship is traversing to push the nozzle flap close. The nozzle also opens when supplied with pressurized air. An air distribution system without a means to close the air distribution nozzle/port will create undue drag when a ship is underway, when not releasing the friction reducing air bubbles.

[0055] 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 sea chest forming the nozzle assembly along with a substantially flush-fitting flap.

[0056] 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.

[0057] To achieve nozzle activation, one or more air compressors within a ship will supply pressurized air to the nozzle. Pressure may be modulated at one or more valves upstream of the nozzle, to supply a variable supply of air, offering different flow rates at different nozzles to compensate for real-time sea conditions. The flow at each nozzle facilitates opening one or more flap mechanisms affixed onto the nozzle assembly main body. Once open, the nozzle assists in 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.

[0058] Air distribution is monitored by air flow/pressure sensors just prior to the nozzles, which provides real-time feedback to a control module, which can then modulate one or more of the previously mentioned valves to deliver more air to nozzles with the most hydrodynamically efficient effect on the hull. The system also utilizes sensors to monitor sea state conditions of the vessel and predictive modeling to optimize where air is needed or will be needed. The system utilizes computational fluid dynamic (CFD) analysis in predictive modeling.

[0059] 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.

[0060] 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.

[0061] Related patent application, U.S. Serial Number 18/119,324, now US12,097,932, 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.

[0062] For this implementation, one must appreciate the physics behind air plastron creation. Water is 50 times denser 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.

[0063] 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.

[0064] 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.

[0065] 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.

[0066] 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.

[0067] 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 provides for self-closing by leveraging the hydrodynamic force of the water the vessel is pressed against for constricting the output size of the nozzle or closing the nozzle altogether.

[0068] Related patent application, U.S. Serial Number 18/219,375, entitled "A System And Method For Delivering Air To A Submerged Ship Surface", discloses the above elements in further detail, all of which are incorporated in its entirety, herein.

[0069] The bow thruster cover assembly comprises a selectively actuatable barrier mechanism positioned at one or both apertures of a bow thruster tunnel that traverses the hull of a marine vessel. These covers can be implemented through various mechanical configurations, including but not limited to hinged doors, retractable panels, articulated louvers, or sliding mechanisms, all designed to modulate the hydrodynamic properties of the bow thruster tunnel during vessel operation.

[0070] When deployed in their closed position, the bow thruster covers substantially reduce parasitic drag that typically occurs within an open thruster tunnel. This drag reduction is achieved by preventing water ingress and subsequent turbulent flow through the tunnel when the thruster is not in active operation. The covers can be engineered with varying degrees of closure, from complete sealing to partial obstruction, depending on the specific operational requirements of the vessel and its air lubrication system.

[0071] The integration of bow thruster covers within an automated air lubrication system represents a sophisticated approach to drag reduction. The covers operate in concert with the air lubrication system through an intelligent control interface that monitors multiple parameters including vessel speed, trim angle, draft, and local water conditions. This integration allows for dynamic optimization of both systems to maximize overall drag reduction and energy efficiency.

[0072] The control system employs sensors to monitor the pressure differential across the bow thruster tunnel, water flow characteristics, and air injection patterns. This data is processed in real-time to determine optimal cover positions that complement the air lubrication system's operation. The control algorithm can adjust cover positions incrementally, allowing for fine-tuned optimization of water flow patterns around the air injection nozzles.

[0073] Careful design of the cover geometry can promote stratification of water flow in the vicinity of air lubrication nozzles. This stratification is crucial for maintaining laminar flow characteristics in the boundary layer where air injection occurs. The covers can be engineered with flow-conditioning features such as vortex generators or flow

straighteners that help organize the water flow patterns before they interact with the injected air bubbles.

[0074] The bow thruster covers can be designed with variable positioning capabilities that allow them to create optimal flow conditions for different vessel operating states. For instance, at higher speeds, the covers might maintain a slightly open position that helps guide water flow in a manner that enhances the effectiveness of the air lubrication system. This controlled flow can help maintain the desired bubble size distribution and coverage area along the hull. When in an open state, an integrated airflow feed nozzle can expel gas from the aft side of the bow thruster cover, allowing air to be delivered at even the most forward portions of the bow, where pounding from the waves is most disruptive to the hydrodynamic efficiency of the hull. In these implementations, some covers may include a hollow portion to help facilitate the flow of air.

[0075] In some other similar implementations, the bow thruster covers are not hollow, but instead, air is delivered just forward of the bow thruster cover doors by an air jet installed forward of the bow thruster cover door to deliver a precisely controlled air supply to interact with the bow thruster cover, and any superaerophilic coating which may be applied to the bow thruster cover door.

[0076] Implementation of the covers can include pressure-relief mechanisms that automatically modulate their position in response to varying hydrodynamic conditions. These mechanisms ensure that the covers maintain optimal flow characteristics while preventing excessive strain on the actuation system. The pressure-relief feature also serves as a safety mechanism, preventing structural damage in extreme conditions.

[0077] The cover system can incorporate feedback mechanisms that continuously monitor the effectiveness of air bubble distribution and adjust accordingly. Sensors placed

downstream of the air injection nozzles can measure bubble size, distribution, and persistence, allowing the control system to optimize cover positions for maximum air lubrication efficiency. This adaptive control ensures that the system maintains optimal performance across varying operational conditions.

[0078] Material selection for the covers plays a crucial role in their performance and longevity. The covers can be constructed from corrosion-resistant materials that maintain their hydrodynamic properties over extended periods. Surface treatments or coatings can be applied to the covers to further reduce friction and prevent marine growth, as discussed above, ensuring consistent performance of both the covers and the air lubrication system.

[0079] Advanced manufacturing techniques can be employed to create cover surfaces with microscale features that enhance their interaction with the water flow. These features might include riblets, dimples, or other surface modifications that help maintain laminar flow and reduce drag. The specific geometry of these features can be optimized for different vessel types and operating conditions.

[0080] The bow thruster covers can be designed with redundant actuation systems to ensure reliable operation in all conditions. These might include primary hydraulic or electric actuators with mechanical backup systems. The control system monitors actuator health and can switch between systems as needed to maintain optimal cover positioning and operation of the air lubrication system.

[0081] Feedback of the cover system may be provided to the vessel's broader operating systems allows for predictive maintenance and performance optimization. The control system can track cover operation over time, identifying patterns that might indicate maintenance requirements or opportunities for efficiency improvements. This data can

also be used to refine control algorithms and improve overall system performance. However, in an ideal implementation, the system controlling the bow thruster covers will be federated to the intelligent air lubrication system, iALS, so that the system is independent of ship operations, whereby the system may receive one-way communication to remain independent of ship system malfunctions.

[0082] The importance of bow thruster covers in managing water flow turbulence cannot be overstated, particularly in the context of air lubrication systems. In an uncovered bow thruster tunnel, water entering the tunnel undergoes significant turbulence due to the sudden change in flow geometry and the presence of the thruster mechanism. This turbulence is characterized by chaotic fluctuations in fluid velocity and pressure, resulting in the formation of eddies and vortices within the tunnel.

[0083] As the vessel moves through the water, this turbulent flow exits the tunnel and interacts with the surrounding water along the hull. The region where this turbulent outflow meets the air lubrication system's nozzles is particularly critical. The nozzles, typically designed to operate in relatively smooth, laminar flow conditions, are tasked with introducing a layer of air bubbles at the boundary layer between the hull and the water. This air layer, when properly maintained, acts to reduce skin friction drag along the hull.

[0084] However, when turbulent water from an uncovered bow thruster tunnel reaches these nozzles, it disrupts the carefully calibrated air injection process. The chaotic motion of the turbulent water can cause irregular air bubble formation, leading to inconsistent bubble sizes and distribution patterns. Large eddies can momentarily increase local pressure at the nozzle outlets, potentially blocking air flow or causing erratic bubble release. Smaller scale turbulence can cause premature bubble breakup, reducing the effectiveness of the air layer.

[0085] Furthermore, the turbulent water flow can interfere with the adherence of the air bubbles to the hull surface. In optimal conditions, the air bubbles form a relatively stable layer that moves along the hull, continuously replenished by the nozzles. Turbulent flow can strip these bubbles away from the hull surface prematurely, preventing the formation of a consistent air layer. This results in patchy coverage, with some areas of the hull benefiting from air lubrication while others remain fully exposed to water friction.

[0086] The disruption caused by turbulent flow from an uncovered bow thruster tunnel can extend well beyond the immediate vicinity of the tunnel exit. The turbulence can propagate downstream along the hull, affecting air lubrication effectiveness over a significant portion of the vessel's length. This extended impact zone further emphasizes the importance of managing flow characteristics at the bow thruster tunnel.

[0087] By implementing a well-designed bow thruster cover system, these turbulence-related issues can be substantially mitigated. The covers, when closed, prevent water flow ingress into the tunnel, eliminating it as a source of turbulence. When partially open or equipped with flow-conditioning features, the covers can help manage and smooth the water flow around the tunnel area, providing a more favorable environment for the operation of the air lubrication nozzles.

[0088] The synergy between the bow thruster cover system and the air lubrication system extends beyond mere turbulence reduction. An intelligently controlled cover system can actively contribute to optimizing the performance of the air lubrication system. By modulating the cover position, the control system can fine-tune local water flow characteristics to enhance bubble formation, adherence, and distribution. This level of control allows for adaptation to varying vessel speeds, loads, and water conditions,

ensuring consistent air lubrication performance across a wide range of operational scenarios.

[0089] The intersection of all of these systems play a role in providing a system and method for enhanced marine vessel efficiency using integrated hull optimizations. The system and method for enhanced marine vessel efficiency using integrated hull optimizations of the present invention may be used to provide a system for reducing hydrodynamic drag on marine vessels through integrated hull optimizations including automated air lubrication control and dynamically adjustable hull features, to provide a bow thruster cover assembly that reduces turbulence and enables strategic air distribution at the forward sections of a marine vessel while maintaining operational functionality of the bow thruster, and to provide an intelligent control system that optimizes air distribution and hull feature positions based on real-time sea state conditions and computational fluid dynamic analysis to maintain maximum efficiency during vessel operation. This apparatus and system are particularly shown in **FIGS. 1-21**.

[0090] **FIG. 1** illustrates a cross-sectional side view of the active system **200** as implemented in a marine vessel **124**. The system includes an automated air distribution system **168** comprising compressors **160** with distributed automation-control modules **162** connected via air conduits **166** to air lubrication nozzles **126** and bow thruster covers **100/102**. The vessel may include a hull **120** with a bulbous bow **150a** and strategically positioned air jets **148**. The control architecture includes sea state sensors such as Doppler **174**, gyro **176**, radar **180**, and GPS units **178**, all connected to a central user interface **172** and control module **173**.

[0091] **FIG. 2** illustrates a diagram view of the control system architecture **200**. The central automation-control module **173** includes a processor **173a**, memory **173b**, and

input/output connections **173c** interfacing with multiple system components. These components include sea state sensors (Doppler **174**, gyro **176**, GPS **178**, radar **180**), air monitoring sensors (temperature **182**, speed **184**, pressure **186**), compressor control modules **162**, valve control modules **170**, actuator control modules **188**, and the user interface module **172**. The automated air distribution system **168** coordinates air flow through compressors **160**, valves **164**, and conduits **166** to nozzles **126** and bow thruster covers **100**.

[0092] **FIG. 3** illustrates a partial bottom view of the bow **150** and bulbous bow **150a** section of the marine vessel hull **120**, showing the strategic layout of air lubrication nozzles **126** and bow thruster covers **100/102** to optimize hydrodynamic efficiency.

[0093] **FIG. 4A** illustrates a side view of an air lubrication nozzle **126** disbursing air under the hull **120** of the ship in a submerged environment **136**. The nozzle assembly includes an open cavity **132**, gas flow inlet **138**, and a flow modulating nozzle flap **128**. The gaseous flow **142** creates an air-interface boundary **140a**, establishing an engaged air layer **144** along the hull surface.

[0094] **FIG. 4B** illustrates a side view of an air lubrication nozzle **126** disbursing air under the hull **120** with a superaerophilic inducing surface **110/122**. The hydrodynamically optimized surface **122** maintains an engaged air layer **144** more effectively than standard hull surfaces.

[0095] **FIG. 5** illustrates an isometric bottom view of an air lubrication nozzle **126** in an opened position. The assembly includes a gas flow inlet **138**, flow modulating nozzle flap **128**, longitudinal engagement area **134**, open cavity **132**, and open lower boundary **140**.

[0096] FIG. 6 illustrates an isometric bottom view of a marine vessel hull 120 with a recessed nozzle assembly 126. The configuration shows the relationship between the hull surface 120a, open cavity 132, air-interface boundary 140a, flow modulating flap 128, and lower horizontal plane 140b of the submerged hull.

[0097] FIG. 7 illustrates an isometric bottom view of an air lubrication nozzle 126 in a closed position, showing the main body 130 and flow modulating nozzle flap 128 in its closed configuration.

[0098] FIG. 8 illustrates an isometric bottom view of a marine vessel hull 120 with a recessed nozzle 126 in a closed position. The hydrodynamically optimized surface 122 shows the integration of the main body 130, hull surface 120a, longitudinal engagement area 134, flow modulating flap 128, and lower horizontal plane 140b.

[0099] FIG. 9 illustrates a front cross-sectional view of a transverse tunnel 116 and bow thruster assembly 190. The configuration shows the hull 120, bow section 150, and tunnel openings 116a/116b with their respective apertures 114.

[0100] FIG. 10 illustrates a front cross-sectional view of the transverse tunnel 116 end sections, showing distal bow thruster covers 102 with their rotational axes 115b at distal openings 116a/116b.

[0101] FIG. 11A illustrates a side view of a louvred-style transverse tunnel cover 102 mounted to the hull 120 in an open state 113b, allowing fluid flow through the tunnel 116.

[0102] FIG. 11B illustrates a side view of a louvred-style transverse tunnel cover 102 in a closed state 113a, showing the moveable parallel panels 112/112b forming a continuous external surface 104 flush with the hull 120.

[0103] FIG. 12A illustrates a side view of the components of a louvred-style transverse tunnel cover 102, showing the actuator/motor 118/152b configuration, with the cover 102 in an open state.

[0104] FIG. 12B illustrates a side view of the components of a louvred-style transverse tunnel cover 102, showing the external surface 104 and actuator/motor 118/152b configuration, with the cover 102 in a closed state.

[0105] FIG. 13A illustrates a side view of a pivot-style transverse tunnel cover 102 mounted to the hull 120 in a closed state 113b.

[0106] FIG. 13B illustrates a side view of a pivot-style transverse tunnel cover 102 in an open state 113a, showing the circular door 112/112a, external surface 104, and its relationship to the hull 120.

[0107] FIG. 14A illustrates a side view of the components of a pivot-style transverse tunnel cover 102, showing the circular door 112/112a, external surface 104, actuator/motor 118/152a, and integral shaft 115a, with the cover 102 shown in a closed state.

[0108] FIG. 14B illustrates a side view of the components of a pivot-style transverse tunnel cover 102, showing the actuator/motor 118/152a and integral shaft 115a configuration, with the cover 102 shown in an open state.

[0109] FIG. 15A illustrates an enlarged isometric view of a pivot-style transverse tunnel cover 102 in a partially open state, showing the hull 120, bow section 150, hydrodynamically optimized surface 122, circular door 112a, external surface 104, and air discharge port 156a with its interior edge 158a.

[0110] FIG. 15B illustrates an enlarged isometric view of a louvred-style transverse tunnel cover 102 in a partially open state, showing the bow section 150, external surface

104, hull **120**, hydrodynamically optimized surface **122**, and air discharge ports **156b** with their interior edges **158b**.

[0111] **FIG. 16** illustrates a side view of multiple louvred-style transverse tunnel covers **102** in a closed state, showing the external surfaces **104**, bow section **150**, hull **120**, and an air jet **148** distributing an air flow **142a/144** across the external surfaces.

[0112] **FIG. 17A** illustrates a front cross-sectional view of a transverse tunnel cover **102** in a closed state, showing the transverse tunnel **116**, hull **120**, external surface **104**, hydrodynamically optimized surface **122** with supraaerophilic inducing surface **110** in the submerged environment **136**.

[0113] **FIG. 17B** illustrates an enlarged front cross-sectional view of a transverse tunnel cover in a closed state, detailing the supraaerophilic texture with microscopic structures **106** including ridges **106b**, trenches **106a**, and protruding structures **106c**, as well as nanoscopic structures **108** with trenches **108a** and ridges **108b**.

[0114] **FIG. 18A** illustrates a partial flow chart of a method **300** for increasing efficiency of a watercraft by reducing drag, showing steps **302-329** including configuring **302**, providing air delivery nozzles **304**, providing nozzle assemblies **306**, providing stratified flow **308**, providing tunnel covers **310**, configuring boundaries **322-324**, providing engagement areas **326**, providing flaps **328**, and coupling components **329**.

[0115] **FIG. 18B** illustrates a partial flow chart of the method **300**, continuing the flow chart from **FIG. 18A**, showing steps **318-352** including providing covers **320**, optimizing surfaces **350**, providing control modules **342**, providing actuation means **340**, providing valves **338**, and configuring the transverse tunnels **318**.

[0116] **FIG. 18C** illustrates a final part of the partial flow chart of the method **300**, as continued from **FIGS. 18A** and **18B** showing steps **312-362** including selecting cover

styles **312-313**, configuring circular the doors **354**, configuring the parallel panels **356**, providing air jets **358**, configuring panels **360**, and providing discharge ports **362**.

[0117] **FIG. 19** illustrates a flow chart for a method of lowering **330** and raising **332** a nozzle flap, including steps for gas flow control **334** and flow termination **336**.

[0118] **FIG. 20** illustrates a flow chart for a method of expanding or constricting airflow **344/345** to the air lubrication nozzles and actuating cover positions **348** based on modulation parameters **345**.

[0119] **FIG. 21** illustrates a flow chart for method steps of a program **400** for an automated control module, including recording sea state conditions **402**, vessel speed **404**, and air pressure **406**, performing computational analysis **408**, modulating gas flow **410**, increasing **412** and decreasing **414** airflow, and actuating covers **416**.

[0120] In an exemplary embodiment, as may be appreciated in **FIGS. 1-3** and **9-17B**, a drag-reducing marine craft hatch **100** is disclosed. The drag-reducing marine craft hatch **100** comprises a moveable transverse tunnel cover **102** having an external submerged surface **104**. The external submerged surface **104** has a plurality of supraaerophilic inducing microscopic structures **106** and nanoscopic structures **108** imprinted within the external submerged surface **104**, forming a supraaerophilic inducing surface **110**. Each supraaerophilic inducing microscopic structure **106** defines a trench **106a** and a ridge **106b** geometry, wherein each ridge structure **106b** defines a protruding structure **106c**.

[0121] In some embodiments, each supraaerophilic inducing nanoscopic structure **108** defines a trench **108a** and a ridge **108b** geometry covering all surface area of the protruding structures **106c** of each of the supraaerophilic inducing microscopic structure **106**, wherein the surfaces of adjacent ridges **106a** of the microscopic structures **106**,

extending between an intermediate trench **106a** to a respective ridge **106b** peak/top, progressively diverge away to define a V-shaped geometry, as may be seen in **FIG. 17B**.

[0122] In some embodiments, the moveable transverse tunnel cover **102** having an external submerged surface **104** comprises at least one moveable panel **112** positioned at an opening **114** of a transverse tunnel **116**, and a panel rotator **118** capable of actuating each of the at least one moveable panel **112** from a closed position **113a** to an open position **113b**. The closed position **113a** creates a substantially flush closure with surrounding ship hull **120** walls. The open position **113b** creates a through-flow, as may be seen in **FIG. 10**.

[0123] In another exemplary embodiment of the invention, as may be appreciated in **FIGS. 1-16**, a hydrodynamically optimized submerged surface **122** of a marine craft **124** is disclosed. This hydrodynamically optimized surface configuration builds upon the previously discussed principles of reducing turbulence and creating stratified flow patterns, while integrating the air lubrication capabilities described in the technical narrative above. The hydrodynamically optimized submerged surface **122** of a marine craft **124** includes at least one moveable transverse tunnel cover **102** and an air lubrication nozzle assembly **126**. These surfaces **104/128** form a substantially flush closure when not in use to avoid hydrodynamic drag. The air lubrication nozzle assembly **126** includes a main body **130** having an open cavity **132** therein, and a flow modulating nozzle flap **128** coupled to at least one longitudinal engagement area **134**. The air lubrication nozzle assembly **126** is operable in a submerged environment **136**. The main body **130** of the air lubrication nozzle assembly **126** includes a gas flow inlet **138**, and an open lower boundary **140** configured to receive a flow modulating nozzle flap **128**. The flap **128** of the air lubrication nozzle assembly **126** is configured to modulate and balance

a direction and flow rate of a gaseous flow **142**, wherein the flap **128** balances the air flow above with the hydrodynamic flow below. The embodiment also creates an engaged air layer **144** created from an air supply of the gaseous flow **142**. In various implementations, the moveable transverse tunnel cover **102** may be configured in different ways to achieve optimal hydrodynamic performance (as may be appreciated in **FIGS. 11A-16**), including (by way of example and not limitation): as a circular door **112a** with an integral shaft **115a** for rotation, and also including as a series of parallel pivotable panels **112b** forming either a solid surface, as seen in **FIG. 11B**, or louvred channel, as seen in **FIG. 11A**, depending on position, or with integrated air discharge ports **156a/156b** at interior edges **158a/158b** for strategic air distribution, as particularly seen in **FIGS. 15A** or **15B**. Additionally, the system may incorporate air jets **148** positioned forward of the covers, as shown in **FIG. 16**, recessed into the bow section **150**, which may include recessed air jets **148** into the bulbous bow **150a** section, to provide directed gas flow over the cover surfaces **104**.

[0124] Each moveable transverse tunnel cover includes an external submerged surface **104**. In some embodiments, the external submerged surface **104** has a plurality of superaerophilic inducing microscopic and nanoscopic structures **106/108** imprinted within the external submerged surface **104**, forming a superaerophilic inducing surface **110**. Each superaerophilic inducing microscopic structure **106** of the plurality of superaerophilic inducing microscopic and nanoscopic structures **106/108** defines a trench **106a** and a ridge **106b** geometry, wherein each ridge structure **106b** defines a protruding structure **106c**. This structure can be primarily appreciated in **FIGS. 17A-17B**.

[0125] In some embodiments, as shown in **FIGS. 13A-15A** each of the at least one moveable transverse tunnel covers **102** comprises a substantially circular door **112a** portion having a continuous external surface **104** and a shaft **115a** portion integrally

formed therewith, wherein rotation of the door is accomplished by rotating the shaft **115a**. A motor/actuator **152a**, as shown in **FIGS 14A-14B**, can rotate the shaft swinging the door **112a** open and closed.

[0126] In some embodiments, as seen in **FIGS. 11A-12B** and **15-17B**, each transverse tunnel cover **102** comprises a plurality of moveable parallel panels **112b**. Each panel **112b** is pivotable about its longitudinal axis **115b**, whereby the panels form a substantially solid surface **104** when in a closed state. When in an open state, the louvred channel **154** permits fluid flow therethrough. A motor/actuator **152b**, as shown in **FIGS 12A-12B**, can raise and lower an actuation rod **115c** to rotate opened and closed the louvred panels **112b**.

[0127] In some embodiments, as shown in **FIGS. 15A-15B**, the moveable transverse tunnel covers **102** further comprises at least one **112a**, or several **112b**, moveable panel(s) **112**, and an air discharge port **156a/156b** positioned at an interior edge **158a/158b** of each moveable panel **112a/112b**. The air discharge port **156a/156b** provides air distribution when the moveable panel **112a/112b** is partially opened during forward movement of the marine craft **124**.

[0128] In some embodiments, the moveable transverse tunnel covers **102** further comprises an air jet **148** positioned forward of the moveable transverse tunnel cover(s) **102**, wherein the air jet **148** is recessed into a bow **150** section of the marine craft **124**, as shown in **FIG. 16**, which may also include recessed jets **148** into a bulbous bow **150a** if present. The air jet **148** is positioned to disburse a flow **142a** of gas in an aft direction over an exterior surface **104** of the at least one moveable transverse tunnel cover **102**.

[0129] An additional exemplary embodiment of the invention discloses a method **300** for increasing efficiency of a watercraft by reducing drag. Building on the automated

control concepts discussed earlier, this method implements the practical steps needed to achieve the synergistic effects of the integrated system. The method **300** comprises configuring **302** portions of a ship's hull **120** for air delivery to the ship hull's lower surface by providing **304** at least one air delivery nozzle **126**. Each of air delivery nozzle **126** is an air lubrication nozzle assembly **126**. The method **300** includes providing **306** the air lubrication nozzle assembly **126**. The air lubrication nozzle assembly **126** is capable of being immersed continuously in a liquid. The air lubrication nozzle assembly **126** includes a main body **130** having an open cavity **132** therein, wherein the main body **130** includes a gas flow inlet **138**, and an open air-interface boundary **140a** is disposed at a lower horizontal plane **140b** of a submerged hull **120** of a ship surrounding the air-interface boundary **140a**. The air lubrication nozzle assembly **126** is operable in a submerged environment **136**. The method **300** further includes providing **308** a stratified flow of water to the open interface boundary **140a** disposed at the lower horizontal plane **140b** by providing **310** a pair of transverse tunnel covers **102** at distal openings **116a/116b** of a submerged transverse tunnel **116** for each submerged transverse tunnel **116** at a bow **150** of the ship. The water flows over the exposed surface **104** of each transverse tunnel cover **102**, thereby reducing turbulence and hydrodynamic drag caused by non-hydrodynamically optimized surfaces. Each moveable transverse tunnel cover **102** is disposed at a submerged substantially vertical plane, as may be appreciated in **FIGS. 1, 9, and 10**. The method **300** can be enhanced through various optimizations, including: selecting **312** transverse tunnel cover style, including configuring **314** covers as circular doors **112a** with integral shafts **115a**, implementing parallel pivotable panels **112b**, incorporating air discharge ports **156a/156b**, and strategically positioning air jets **148** in the bow section **150**. The method **300** may also include optimizing **316** external surfaces

104 through superaerophilic inducing microscopic structures **106** and nanoscopic structures **108**, providing enhanced water flow characteristics and air retention properties. The implementation can be further refined through electronic valve control and actuation systems that respond to sea state conditions, enabling dynamic adjustment of both air flow and cover positions.

[0130] In some embodiments, the method **300** for increasing efficiency of a watercraft by reducing drag includes configuring **318** any remaining transverse tunnels **116** (with at least one open cavity) for reduced hydrodynamic drag by providing **320** at least one moveable transverse tunnel cover **102**. Each moveable transverse tunnel cover **102** is disposed at a submerged substantially vertical plane. This is particularly important for other cavities and suction lines separate than a bow thruster cover tunnel **116**.

[0131] In some embodiments of the method **300** for increasing efficiency of a watercraft by reducing drag, the step of configuring **302** portions of a ship's hull **120** for air delivery to the ship's hull's lower surface by providing **304** at least one air delivery nozzle **126** further includes configuring **322** the open air-interface boundary **140a** to be substantially coplanar with an adjacent surface **120a** of the marine vessel **124** hull **120**, configuring **324** the open air-interface **140a** to receive a flow modulating nozzle flap **128** by providing **326** a longitudinal engagement area **134**, and providing **328** a flow modulating nozzle flap **128**. The flow modulating nozzle flap **128** is coupled **329** to the at least one longitudinal engagement area **134**. The flap **128** is configured to modulate a direction and flow rate of a gaseous flow **142**. The main body **130** of each nozzle **126** is recessed up into the ship's hull **120**.

[0132] In some embodiments of the method **300** for increasing efficiency of a watercraft by reducing drag, the air lubrication nozzle assembly **126** is capable of

performing the steps of lowering **330** the flow modulating nozzle flap **128** and raising **332** the flow modulating nozzle flap **128**. The step of lowering **330** the flow modulating nozzle flap **128** is accomplished by using a flow of gas **142** received from the gas flow inlet **138** to lower the flow modulating nozzle flap **128**. A flow of gas **142** disburses uniformly in the open cavity **132** of the main body **130**, thereby pressing on the flow modulating nozzle flap **128** to allow air bubbles to disburse to an underside of a marine craft's hull **120**, when air is required under the marine craft's hull **120**. The step of raising **332** the flow modulating nozzle flap **128** is accomplished by terminating **336** a flow of gas **142** received from the gas flow inlet **138**, whereby a passive lifting system is incorporated into the flow modulating nozzle flap **128** allows for self-closure when the air is no longer required under the marine craft's hull **120**. The passive lifting incorporates the flap's **128** natural buoyancy and the flow of water under the flap to keep the flap in a substantially closed position.

[0133] In some embodiments, the method **300** for increasing efficiency of a watercraft by reducing drag further includes providing **338** an electronic valve **164** upstream of each gas flow inlet **138** of each air lubrication nozzle assembly **126**, providing **340** an electronic actuation means **152a/152b** for each moveable transverse tunnel cover **102**, and providing **342** at least one dedicated control module **173** electronically coupled to each electronic valve **164** and each actuation means **152a/152b**. The at least one dedicated control module **173** includes at least one processor **173a**, memory **173b**, and an input/output connection **173c** facilitating the electronic complement, whereby the memory **173b** includes a program stored thereon, including at least the steps of expanding **344** or constricting **346** air flow to each air lubrication nozzle assembly **126** and actuating **348** an opening or closing of each of the moveable transverse tunnel covers

102. Expanding **344** or constricting **346** air flow to each air lubrication nozzle assembly **126** is accomplished by modulating **345** the valve **164** in a position in the range of fully open to fully closed based on feedback of a plurality of sensors measuring sea state conditions (e.g., Doppler **174**, gyro **176**, GPS unit **178**, and radar **180**) to selectively distribute air under the hull **120** of a ship, and actuating **348** an opening or closing of each of the moveable transverse tunnel covers **102** in a position in the range of fully open to fully closed based on feedback of the plurality of sensors.

[0134] In some embodiments, the method **300** for increasing efficiency of a watercraft by reducing drag further includes optimizing **350** at least a portion of each external submerged surface **104** by providing **352** a plurality of supraaerophilic inducing microscopic structures **106** and nanoscopic structures **108** imprinted within the external submerged surface **104**, thereby forming a supraaerophilic inducing surface **110**. Each supraaerophilic inducing microscopic structure **106** of the plurality of supraaerophilic inducing microscopic and nanoscopic structures defines a trench **106a** and a ridge **106b** geometry. Each ridge structure **106b** defines a protruding structure **106c**. Each supraaerophilic inducing nanoscopic structure **108** of the plurality of supraaerophilic inducing microscopic and nanoscopic structures defines a trench **108a** and a ridge **108b** geometry covering all surface area of the protruding structures **106c** of each of the supraaerophilic inducing microscopic structure **106**. The surfaces of adjacent ridges **106b** of the microscopic structures **106**, extends between an intermediate trench **106a** to a respective ridge **106b** peak/top, progressively diverge away to define a V-shaped geometry. Each submerged surface includes an external surface including each the flow modulating nozzle flap **128**, each moveable transverse tunnel cover **102**, and the ship's hull **120**.

[0135] In some embodiments, the method **300** for increasing efficiency of a watercraft by reducing drag further includes configuring **354** each transverse tunnel cover **102** as a substantially circular door **112a** portion having a continuous external surface and a shaft **115a** portion integrally formed therewith, wherein rotation of the door **112a** is accomplished by rotating the shaft **115a**.

[0136] In some embodiments, the method **300** for increasing efficiency of a watercraft by reducing drag further includes configuring **356** each transverse tunnel cover **102** as a plurality of moveable parallel panels **112b**, each pivotable about its longitudinal axis **115b**, whereby the plurality of moveable parallel panels **112b** form a substantially solid exterior surface **104** in a closed state, and a louvred channel **154** in an open state to permit fluid flow therethrough.

[0137] In some embodiments, the method **300** for increasing efficiency of a watercraft by reducing drag further includes selecting **313** the transverse tunnel cover air distribution system, providing **358** at least a pair of air jets **148** positioned forward of the pair of transverse tunnel covers **102**, wherein each the air jet **148** is recessed into a bow section **150** of the marine craft, and each the air jet **148** is positioned to disburse a flow of gas **142a** in an aft direction over an exterior surface **104** of each transverse tunnel cover **102**.

[0138] In some embodiments, the method **300** for increasing efficiency of a watercraft by reducing drag further includes configuring **360** each transverse tunnel cover **102** to have at least one moveable panel **112**. The method **300** also includes providing **362** an air discharge port **156a/156b** positioned at an interior edge **158a/158b** of the moveable panel **112**, whereby the air discharge port **156a/156b** provides air distribution

when the moveable panel **112** is partially opened during forward movement of the marine craft **124**.

[0139] In a further exemplary embodiment, an active system **200** for reducing hydrodynamic drag on a hull **120** of a marine craft active system **124**, is disclosed. Drawing from the computational fluid dynamic analysis principles discussed in the technical narrative, this active system **200** represents the comprehensive integration of all previously discussed components. The system **200** comprises an automated air distribution system **168**, as shown in **FIGS. 1-2**. The automated air distribution system **168** includes at least one compressor **160** with a distributed automation-control module **162**, at least one airflow modulation valve(s) **164**, and at least one air lubrication nozzle **126**. The automated air distribution system **168** couples the one or more compressors **160** to an automated valve **164** utilizing a plurality of air conduits **166**. The automated air distribution system **168** couples each automated valve **164** to at least one air lubrication nozzle **126** using at least one air conduit **166**. Each automated valve **164** includes a distributed automation-control module **170**. The system also includes at least one moveable transverse tunnel cover **102** with an external submerged surface **104**. Each moveable transverse tunnel cover **102** includes a controllable motor and/or actuator **152a/152b**, a user interface module **172**, and a central automation-control module **173** (which may be typically referred to as a central server, or central control computer) electronically coupled to at least each distributed automation-control module **162** on each compressor **160**, each distributed automation-control module **170** at each automated valve **164**, each controllable actuator **152a/152b**, and coupled to the user interface module **172**. The system can incorporate various sensor types and control mechanisms, including sea state sensors (such as Doppler **174**, gyro **176**, GPS units **178**, and radar

180), airflow sensors between the valve **164** and nozzle **126** (such as air temperature sensors **182**, air speed sensors **184**, air pressure sensors **186**), all feeding into the central automation-control module **173**. This module **173** executes sophisticated programs that record conditions, perform computational fluid dynamic analysis, and optimize both air distribution and cover positions in real-time. The system **200** may be implemented with different cover **102** configurations, including circular doors **112a** with integral shafts **115a** or parallel pivotable panels **112b**, each designed to optimize flow characteristics while maintaining system efficiency.

[0140] In some embodiments, each air lubrication nozzle **126**, as seen in **FIGS. 4A-8**, comprises a main body **130** having an open cavity **132** therein, a gas flow inlet **138** in the main body **130**, and an open lower boundary **140** making up an open air-interface boundary **140a** where the airflow interfaces with a hydrodynamic flow disposed at a lower horizontal plane **140b**. The open air-interface boundary **140** is substantially coplanar with an adjacent surface **120a** of the hull **120b**. The main body **130** has at least one longitudinal engagement area **134** at the open air-interface boundary **140a**, and a flow modulating nozzle flap **128** coupled to the longitudinal engagement area **134**. The flow modulating nozzle flap **128** is configured to modulate and balance a direction and flow rate of a gaseous flow **142**.

[0141] In some embodiments, the active system **200** for reducing hydrodynamic drag on a hull **120** of a marine craft **124** further comprises at least one pair of moveable transverse tunnel covers **102** positioned at distal ends **116a/116b** of a transverse tunnel **116**, as may be appreciated in **FIGS. 1, 3, 9, and 10**.

[0142] In some embodiments, each moveable transverse tunnel cover **102** is positioned at distal ends **116a/116b** of the transverse tunnel **116** and comprises a

substantially circular door **112a** portion having a continuous external surface **104**. A shaft **115a** portion is integrally formed therewith, wherein rotation of the door **112a** is accomplished by rotating the shaft **115a**. This can be seen in **FIGS. 13A-15A**.

[0143] In some embodiments, each moveable transverse tunnel cover **102** comprises a plurality of moveable parallel panels **112b**, as may be seen in **FIGS. 11A-12B** and **15B-17A**. Each panel **112b** is pivotable about its longitudinal axis **115b**, whereby the plurality of moveable parallel panels **112b** form a substantially solid external submerged surface **104** in a closed state, and a louvred channel **154** in an open state to permit fluid flow therethrough.

[0144] In some embodiments, each moveable transverse tunnel cover **102** in the pair of moveable transverse tunnel covers positioned at the distal ends of the transverse tunnel comprises a moveable panel **112/112a/112b**. An air discharge port **156a/156b** is positioned at an interior edge **158a/148b** of the moveable panel, as may be seen in **FIGS 15A-15B**. During forward movement of the marine craft **124**, when the moveable panel **112/112a/112b** is partially opened, the air discharge port **156a/156b** provides air distribution. This configuration allows for strategic air delivery at the bow thruster tunnel **116** openings **116a/116b** while maintaining the drag-reducing capabilities of the moveable covers **112/112a/112b**.

[0145] In some embodiments, an air jet **148** is positioned forward of the at least one moveable transverse tunnel cover **102**. The air jet **148** is recessed into a bow section **150** of the marine craft and is positioned to disburse a flow of gas **142a** in an aft direction over the exterior surface **104** of each transverse tunnel cover **102**.

[0146] In some embodiments, the active system **200** for reducing hydrodynamic drag on a hull **120** of a marine craft **124** further comprises at least one sea state sensor

(such as Doppler **174**, gyro **176**, at least one GPS unit **178**, and radar **180**), and at least one air temperature sensors **182**, at least one air speed sensor **184**, at least one air pressure sensors **186**, positioned between each automated valve **164** and each air lubrication nozzle **126**, and a central automation-control module **173**. The central automation-control module **173** has at least a processor **173a**, a memory **173b**, and input/output connections **173c** electronically coupled to each sea state sensor **174**, **176**, **178**, **180**, each speed sensor **184**, each air pressure sensor **186**, each air temperature sensor **182**, each GPS unit **178**, each distributed automation-control module **162** on each compressor **160**, each distributed automation-control module **170** at each automated valve **164**, and each controllable actuator **152a/152b** control module **188**. The connections described are particularly shown in **FIG. 2**.

[0147] In some embodiments, the memory **173b** includes a program **400** stored thereon, whereby once executed by the processor **173a** performs the steps of recording **402** sea state conditions from the at least one sea state sensor (such as Doppler **174**, gyro **176**, at least one GPS unit **178**, and radar **180**), recording **404** vessel speed from the at least one speed sensor **184** and the GPS unit **178**, recording **406** air pressure at each air lubrication nozzle **126** from the at least one air pressure sensor **186**, performing **408** computational fluid dynamic analysis using the recorded sea state conditions and the recorded vessel speed to determine optimal air distribution patterns, modulating **410** a gaseous flow **142** from at least one compressor **160** through at least one automated valve **164** based on the computational fluid dynamic analysis, increasing **412** the gaseous flow **142** to at least one air lubrication nozzle **126** to lower a flow modulating nozzle flap **128** and increase airflow to a targeted area of the hull **120** based on the optimal air distribution patterns, decreasing **414** the gaseous flow **142** to at least one air lubrication nozzle **126**

to raise a flow modulating nozzle flap **128** and decrease airflow based on the optimal air distribution patterns, and actuating **416** at least one moveable transverse tunnel cover **102** based on engagement of a bow thruster **116** and the computational fluid dynamic analysis to optimize water flow patterns around the air lubrication nozzles **126**.

[0148] While there has been shown and described above the preferred embodiment of the instant invention 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.

THE CLAIMS

I claim:

1. A drag-reducing marine craft hatch, comprising:
a moveable transverse tunnel cover having an external submerged surface;
said external submerged surface having a plurality of supraaerophilic inducing microscopic and nanoscopic structures imprinted within said external submerged surface, forming a supraaerophilic inducing surface; and
each supraaerophilic inducing microscopic structure of said plurality of supraaerophilic inducing microscopic and nanoscopic structures defines a trench and a ridge geometry, wherein each ridge structure defines a protruding structure.
2. The drag-reducing marine craft hatch, as recited in Claim 1, wherein each supraaerophilic inducing nanoscopic structure of said plurality of supraaerophilic inducing microscopic and nanoscopic structures defines a trench and a ridge geometry covering all surface area of said protruding structures of each of said supraaerophilic inducing microscopic structure, wherein surfaces of adjacent ridges of the microscopic structures, extending between an intermediate trench to a respective ridge peak/top, progressively diverge away to define a V-shaped geometry.
3. The drag-reducing marine craft hatch, as recited in Claim 1, wherein said moveable transverse tunnel cover having an external submerged surface comprises:
at least one moveable panel positioned at an opening of a transverse tunnel opening; and
a panel rotator capable of actuating each of said at least one moveable panel from a closed position to an open position, wherein said closed position creates a

substantially flush closure with surrounding ship hull walls, and said open position creates a through-flow.

4. A hydrodynamically optimized submerged surface of a marine craft, comprising:
at least one moveable transverse tunnel cover;
an air lubrication nozzle assembly, wherein said air lubrication nozzle assembly includes
a main body having an open cavity therein, a flow modulating nozzle flap coupled
to at least one longitudinal engagement area, wherein said air lubrication nozzle
assembly is operable in a submerged environment;
said main body of said air lubrication nozzle assembly includes a gas flow inlet, and an
open lower boundary configured to receive a flow modulating nozzle flap;
said flap of said air lubrication nozzle assembly is configured to modulate a direction and
flow rate of a gaseous flow; and
an engaged air layer created from an air supply of said gaseous.

5. The hydrodynamically optimized submerged surface of a marine craft, as recited
in Claim 4, wherein each moveable transverse tunnel cover in said at least one moveable
transverse tunnel cover includes an external submerged surface;
said external submerged surface having a plurality of superaerophilic inducing
microscopic and nanoscopic structures imprinted within said external submerged
surface, forming a superaerophilic inducing surface; and
each superaerophilic inducing microscopic structure of said plurality of superaerophilic
inducing microscopic and nanoscopic structures defines a trench and a ridge
geometry, wherein each ridge structure defines a protruding structure.

6. The hydrodynamically optimized submerged surface of a marine craft, as recited in Claim 4, wherein each of said at least one moveable transverse tunnel cover comprises:

a substantially circular door portion having a continuous external surface and a shaft portion integrally formed therewith, wherein rotation of said door is accomplished by rotating said shaft.

7. The hydrodynamically optimized submerged surface of a marine craft, as recited in Claim 4, wherein each of said at least one moveable transverse tunnel cover comprises:

a plurality of moveable parallel panels, each pivotable about its longitudinal axis, whereby said plurality of moveable parallel panels form a substantially solid surface in a closed state, and a louvred channel in an open state to permit fluid flow therethrough.

8. The hydrodynamically optimized submerged surface of a marine craft, as recited in Claim 4, wherein said at least one of said moveable transverse tunnel covers further comprises:

a moveable panel; and

an air discharge port positioned at an interior edge of said moveable panel, whereby said air discharge port provides air distribution when said moveable panel is partially opened during forward movement of said marine craft.

9. The hydrodynamically optimized submerged surface of a marine craft, as recited in Claim 4, further comprising:

an air jet positioned forward of said at least one moveable transverse tunnel cover, wherein said air jet is recessed into a bow section of said marine craft, and said air jet is positioned to disburse a flow of gas in an aft direction over an exterior surface of said at least one moveable transverse tunnel cover.

10. A method for increasing efficiency of a watercraft by reducing drag, the method comprising:

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

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

a main body having an open cavity therein, wherein said main body includes a gas flow inlet, and an open air-interface boundary is disposed at a lower horizontal plane of a submerged hull of a ship surrounding said air-interface boundary; and

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

providing a stratified flow of water to said open interface boundary disposed at said lower horizontal plane by providing a pair of transverse tunnel covers at distal openings of a submerged transverse tunnel for each submerged transverse tunnel at a bow

of said ship, whereby water flows over an exposed surface of each transverse tunnel cover thereby reducing turbulence and hydrodynamic drag caused by non-hydrodynamically optimized surfaces; and
wherein each of said moveable transverse tunnel covers is disposed at a submerged substantially vertical plane.

11. The method for increasing efficiency of a watercraft by reducing drag, as recited in Claim 10, further comprising the step of:
configuring any remaining transverse tunnels with at least one open cavity for reduced hydrodynamic drag by providing at least one moveable transverse tunnel cover, wherein each of said at least one moveable transverse tunnel cover is disposed at a submerged substantially vertical plane.

12. The method for increasing efficiency of a watercraft by reducing drag, as recited in Claim 10, wherein said step of configuring portions of a ship's hull for air delivery to said ship's hull's lower surface by providing at least one air delivery nozzle further includes:
configuring said open air-interface boundary to be substantially coplanar with an adjacent surface of the marine vessel hull;
configuring said open air-interface to receive a flow modulating nozzle flap by providing a longitudinal engagement area;
providing a flow modulating nozzle flap, whereby said flow modulating nozzle is coupled to said at least one longitudinal engagement area, wherein said flap is configured to modulate a direction and flow rate of a gaseous flow; and
wherein the main body of each nozzle is recessed up into the ship's hull.

13. The method for increasing efficiency of a watercraft by reducing drag, as recited in Claim 12, 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.

14. The method for increasing efficiency of a watercraft by reducing drag, as recited in Claim 10, further comprising:

providing an electronic valve upstream of each gas flow inlet of each air lubrication nozzle assembly;

providing an electronic actuation means for each moveable transverse tunnel cover; and

providing at least one dedicated control module electronically coupled to each electronic valve and each actuation means, wherein said at least one dedicated control module includes at least one processor, memory, and an input/output connection facilitating said electronic couplement, whereby said memory includes a program stored thereon, including at least the steps of:

expanding or constricting air flow to each air lubrication nozzle assembly by modulating the valve in a position in the range of fully open to fully closed based on feedback of a plurality of sensors measuring sea state conditions to selectively distribute air under the hull of a ship; and actuating an opening or closing of each of said moveable transverse tunnel covers in a position in the range of fully open to fully closed based on feedback of a plurality of sensors measuring sea state conditions to selectively distribute air under the hull of a ship.

15. The method for increasing efficiency of a watercraft by reducing drag, as recited in Claim 14, further comprising:

optimizing at least a portion of each external submerged surface by providing a plurality of superaerophilic inducing microscopic and nanoscopic structures imprinted within said external submerged surface, forming a superaerophilic inducing surface;

each superaerophilic inducing microscopic structure of said plurality of superaerophilic inducing microscopic and nanoscopic structures defines a trench and a ridge geometry, wherein each ridge structure defines a protruding structure;

wherein each superaerophilic inducing nanoscopic structure of said plurality of superaerophilic inducing microscopic and nanoscopic structures defines a trench and a ridge geometry covering all surface area of said protruding structures of each of said superaerophilic inducing microscopic structure, wherein surfaces of adjacent ridges of the microscopic structures, extending between an intermediate

trench to a respective ridge peak/top, progressively diverge away to define a V-shaped geometry; and

wherein each submerged surface includes an external surface of each said flow modulating nozzle flap, each moveable transverse tunnel cover, and said ship's hull.

16. The method for increasing efficiency of a watercraft by reducing drag, as recited in Claim 10, further comprising:

configuring each transverse tunnel cover as a substantially circular door portion having a continuous external surface and a shaft portion integrally formed therewith, wherein rotation of said door is accomplished by rotating said shaft.

17. The method for increasing efficiency of a watercraft by reducing drag, as recited in Claim 10, further comprising:

configuring each transverse tunnel cover as a plurality of moveable parallel panels, each pivotable about its longitudinal axis, whereby said plurality of moveable parallel panels form a substantially solid surface in a closed state, and a louvred channel in an open state to permit fluid flow therethrough.

18. The method for increasing efficiency of a watercraft by reducing drag, as recited in Claim 10, further comprising the step of:

providing at least a pair of air jets positioned forward of said pair of transverse tunnel covers, wherein each said air jet is recessed into a bow section of said marine

craft, and each said air jet is positioned to disburse a flow of gas in an aft direction over an exterior surface of each transverse tunnel cover.

19. The method for increasing efficiency of a watercraft by reducing drag, as recited in Claim 10, further comprising:

configuring each transverse tunnel cover to have at least one moveable panel; and providing an air discharge port positioned at an interior edge of said moveable panel, whereby said air discharge port provides air distribution when said moveable panel is partially opened during forward movement of said marine craft.

20. An active system for reducing hydrodynamic drag on a hull of a marine craft, the system comprising:

an automated air distribution system, wherein said automated air distribution system includes at least one compressor with a distributed automation-control module, at least one airflow modulation valves, and at least one air lubrication nozzle; said automated air distribution system coupling each of said at least one compressors to an automated valve with a plurality of air conduits; said automated air distribution system coupling each of said automated valve to at least one of said air lubrication nozzles with at least one air conduit; each automated valve including a distributed automation-control module; at least one moveable transverse tunnel cover having an external submerged surface, wherein each moveable transverse tunnel cover includes a controllable actuator; a user interface module; and

a central automation-control module electronically coupled to at least each distributed automation-control module on each compressor, each distributed automation-control module at each automated valve, each controllable actuator, and coupled to said user interface module.

21. The active system for reducing hydrodynamic drag on a hull of a marine craft, as recited in Claim 20, wherein each air lubrication nozzle comprises:

a main body having an open cavity therein;

a gas flow inlet in said main body;

an open air-interface boundary disposed at a lower horizontal plane, wherein said open air-interface boundary is substantially coplanar with an adjacent surface of said hull;

at least one longitudinal engagement area at said open air-interface boundary; and

a flow modulating nozzle flap coupled to said at least one longitudinal engagement area, wherein said flow modulating nozzle flap is configured to modulate a direction and flow rate of a gaseous flow.

22. The active system for reducing hydrodynamic drag on a hull of a marine craft, as recited in Claim 20, further comprising:

at least one pair of moveable transverse tunnel covers positioned at distal ends of a transverse tunnel.

23. The active system for reducing hydrodynamic drag on a hull of a marine craft, as recited in Claim 22, wherein each moveable transverse tunnel cover in said at least one

pair of moveable transverse tunnel covers positioned at distal ends of said transverse tunnel comprises:

a substantially circular door portion having a continuous external surface and a shaft portion integrally formed therewith, wherein rotation of said door is accomplished by rotating said shaft.

24. The active system for reducing hydrodynamic drag on a hull of a marine craft, as recited in Claim 22, wherein each moveable transverse tunnel cover in said at least one pair of moveable transverse tunnel covers positioned at distal ends of said transverse tunnel comprises:

a plurality of moveable parallel panels, each pivotable about its longitudinal axis, whereby said plurality of moveable parallel panels form a substantially solid surface in a closed state, and a louvred channel in an open state to permit fluid flow therethrough.

25. The active system for reducing hydrodynamic drag on a hull of a marine craft, as recited in Claim 22, wherein each moveable transverse tunnel cover in said at least one pair of moveable transverse tunnel covers positioned at distal ends of said transverse tunnel comprises:

a moveable panel; and

an air discharge port positioned at an interior edge of said moveable panel, whereby said air discharge port provides air distribution when said moveable panel is partially opened during forward movement of said marine craft.

26. The active system for reducing hydrodynamic drag on a hull of a marine craft, as recited in Claim 22, further comprising:

an air jet positioned forward of said at least one moveable transverse tunnel cover, wherein said air jet is recessed into a bow section of said marine craft, and said air jet is positioned to disburse a flow of gas in an aft direction over an exterior surface of said at least one moveable transverse tunnel cover.

27. The active system for reducing hydrodynamic drag on a hull of a marine craft, as recited in Claim 20, further comprising:

at least one sea state sensor;

at least one speed sensor;

at least one air pressure sensor positioned between each automated valve and each air lubrication nozzle;

at least one GPS unit;

said central automation-control module having at least a processor, a memory, and input/output connections electronically coupled to each sea state sensor, each speed sensor, each air pressure sensor, each GPS unit, each distributed automation-control module on each compressor, each distributed automation-control module at each automated valve, and each controllable actuator, wherein said memory includes a program stored thereon, whereby once executed by the processor comprises the steps of:

recording sea state conditions from said at least one sea state sensor;

recording vessel speed from said at least one speed sensor and said GPS unit;

recording air pressure at each air lubrication nozzle from said at least one air pressure sensor;

performing computational fluid dynamic analysis using said recorded sea state conditions and said recorded vessel speed to determine optimal air distribution patterns;

modulating a gaseous flow from at least one compressor through at least one automated valve based on said computational fluid dynamic analysis;

increasing said gaseous flow to at least one air lubrication nozzle to lower a flow modulating nozzle flap and increase airflow to a targeted area of said hull based on said optimal air distribution patterns;

decreasing said gaseous flow to at least one air lubrication nozzle to raise a flow modulating nozzle flap and decrease airflow based on said optimal air distribution patterns; and

actuating at least one moveable transverse tunnel cover based on engagement of a bow thruster and said computational fluid dynamic analysis to optimize water flow patterns around said air lubrication nozzles.