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(54) **HYDROFOIL WATERCRAFT WITH ARCUATE RETRACTABLE STRUT SYSTEM**

(57) A watercraft configured for hydrofoil operation includes a flotation structure and one or more hydrofoil struts that transition between deployed and stowed configurations along arcuate paths about radial axes positioned outside the flotation structure. The arcuate retraction geometry enables the struts to sweep longitudinally within the hull envelope, providing compact stowed profiles without deep vertical hull cavities or lateral protrusion, while the continuous curved strut geometry provides a structurally rigid load path that inherently resists bending forces during foiling. Pitch-axis pivot joints at the strut distal ends decouple foil orientation from strut angle, permitting the hydrofoil lift surfaces to maintain a substantially horizontal orientation during partial retraction for shallow-water foiling. Forward-facing and downward-facing underwater sensors enable automatic hazard-responsive retraction. A control system autonomously maintains ride height. The watercraft may further be configured for unmanned autonomous operation with GPS waypoint-following navigation and a payload mounting interface.

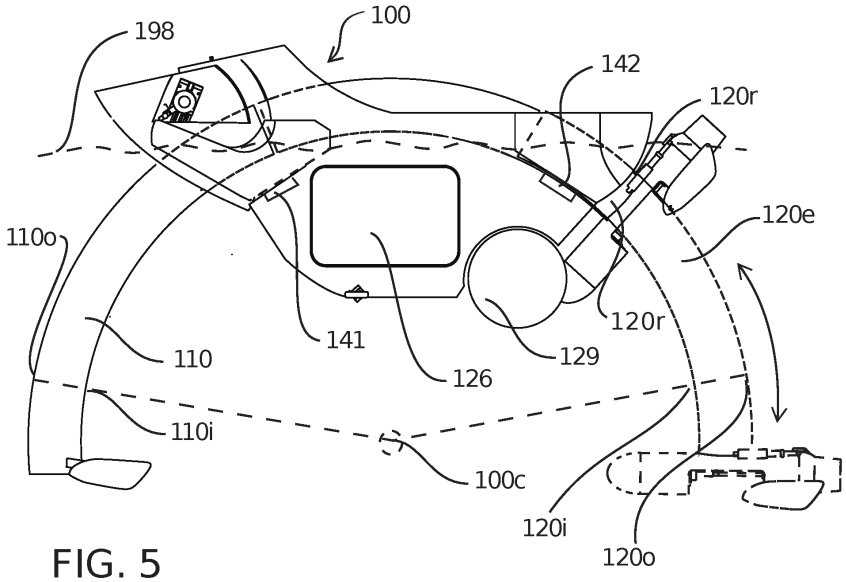


FIG. 5

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Description

PRIORITY CLAIM

[0001] This application claims priority from U.S. Provisional Application No. 63/773,001, filed 17 March 2025, entitled "Watercraft With Retractable Lift Structures', under the Paris Convention.

[0002] This application is related to Chinese Utility Model Application No. 202520598462.1, filed 1 April 2025, entitled 'A Watercraft with Retractable Lift Structures', which also claims priority from U.S. Provisional Application No. 63/773,001.

TECHNICAL FIELD

[0003] The present invention relates generally to watercraft (also referred to herein as a hydrofoil vehicle or vehicle) configured for hydrofoil operation, and more particularly to hydrofoil systems incorporating retractable hydrofoil struts (also referred to herein as arcuate struts or struts) capable of transitioning between operational hydrodynamic configurations and compact stowed configurations along arcuate deployment paths about external radial axes.

BACKGROUND ART

[0004] Hydrofoil watercraft utilize submerged lifting surfaces positioned beneath a hull or flotation structure. As forward velocity increases, hydrodynamic lift generated by the hydrofoil surfaces raises the hull above the water surface, thereby reducing wetted surface area, lowering hydrodynamic drag, and improving efficiency and speed. Personal electric hydrofoil watercraft have emerged as a growing segment in the marine recreational market.

[0005] While hydrofoil systems offer performance advantages, conventional hydrofoil architectures present practical challenges related to transport, docking, shallow water operation, and storage. Many hydrofoil craft incorporate fixed hydrofoil struts that extend beneath the hull at all times. Such configurations can prevent operation in shallow water environments, complicate transport on trailers, increase the likelihood of damage during docking or launching, and result in watercraft that cannot be stored in standard residential garages or transported in the cargo area of typical passenger vehicles, or easily stored on yachts.

[0006] Certain retractable hydrofoil structures have been proposed. Some approaches move hydrofoil structures substantially vertically relative to a hull. Such configurations may require significant internal hull volume arranged along a vertical axis, increasing overall hull depth, and hull height adding structural weight, and reducing available interior volume. Other approaches move hydrofoil assemblies laterally relative to a hull. Such configurations may result in hydrofoil elements protruding beyond the beam of the vessel when stowed, increasing the overall lateral footprint and potentially preventing transport through standard doorways or storage in vehicle cargo areas.

[0007] There exists a need for improved hydrofoil retraction architectures that enable compact storage and transport without requiring large vertical cavities within the hull or significant increases in lateral beam, while also supporting the structural, electrical, and control system requirements of modern actively stabilized hydrofoil watercraft and providing enhanced safety through sensor-responsive retraction capability.

DISCLOSURE OF THE INVENTION

[0008] The technical problem addressed by the present disclosure is to provide a hydrofoil watercraft in which the hydrofoil lift structures can be retracted into a compact stowed configuration without requiring deep vertical cavities within the hull, while maintaining structural rigidity during foiling and enabling transport through standard residential doorways. To solve this problem, The following summary is provided to introduce the reader to the more detailed description to follow and not to limit or define any claimed or as yet unclaimed invention. One or more inventions may reside in any combination or subcombination of the elements or process steps disclosed in any part of this document including its claims and figures.

[0009] The present invention addresses the above-described limitations by providing a fundamentally different hydrofoil retraction architecture: arcuate retraction about an external radial axis. The hydrofoil struts of the present invention move along arcuate paths defined about radial axes that are positioned outside an outer boundary of the flotation structure. This arcuate retraction geometry enables the struts to sweep longitudinally within the hull envelope along curved trajectories, yielding compact stowed profiles without requiring deep vertical cavities within the flotation structure or lateral protrusion beyond the vessel beam. The arcuate geometry further provides a continuous curved structural load path from the flotation structure to the submerged hydrofoil lift surfaces, inherently resisting the bending forces encountered during high-speed foiling operation along the entire arc length of the strut. A guide structure constrains the strut to move along a curved path relative to the hull, changing both the vertical and longitudinal position of a hydrofoil relative to the hull.

[0010] In one aspect, a watercraft configured for hydrofoil operation includes a flotation structure and one or more hydrofoil struts operatively coupled to the flotation structure, each hydrofoil strut supporting a respective hydrofoil lift surface at a distal end thereof. Each hydrofoil strut is movable between a deployed configuration (also referred to herein as the extended position) in which the respective hydrofoil lift surface is positioned beneath the flotation structure to generate hydrodynamic lift, and a

stowed configuration (also referred to herein as the retracted position) in which the hydrofoil strut is at least partially received within or against the flotation structure. The transition between the deployed and stowed configurations follows an arcuate path about a radial axis positioned outside an outer boundary of the flotation structure, such that the hydrofoil struts sweep longitudinally within an envelope of the flotation structure during retraction. As used herein, the outer boundary of the flotation structure refers to the outermost physical surface or envelope of the flotation structure, such that the radial axis is positioned in space outside and below this outermost surface. The deployed configuration may also be referred to as a deployed position, and the stowed configuration may also be referred to as a retracted position.

[0011] In some embodiments, the watercraft includes a pitch-axis pivot joint rotatably coupling each hydrofoil lift surface to its respective arcuate strut, permitting the lift surface to maintain a substantially horizontal orientation during partial retraction. The watercraft may include active control surfaces, height-above-water sensors, inertial measurement units, and underwater ultrasonic transducers enabling autonomous ride height control and hazard-responsive retraction.

[0012] In another aspect, a watercraft includes a flotation structure, at least one hydrofoil, at least one active control surface, and a control system comprising at least one inertial measurement unit (including one or more accelerometers and one or more gyroscopes), at least one height-above-water sensor, and a controller. The controller is configured to implement a sensor fusion algorithm that combines data from the inertial measurement unit and the height-above-water sensor to estimate the vehicle attitude and height in real time, and to autonomously adjust the at least one active control surface based on the fused sensor data to maintain a target ride height above the water surface. The controller may further implement automatic stabilization using feedback control algorithms including proportional-integral-derivative (PID) control, model-predictive control, linear-quadratic regulation, or neural network-based control. The controller may operate in a plurality of operational states including at least an idle state, a takeoff transition state, a foiling state, a landing transition state, and a degraded or fail-safe state.

[0013] In further aspects, the stowed configuration may occupy a transverse width permitting passage through a standard residential doorway. The arcuate retraction path produces both vertical displacement and longitudinal displacement, with the longitudinal displacement exceeding the vertical displacement, enabling compact stowage without deep vertical hull cavities. The longitudinal displacement may exceed the vertical displacement during the retraction motion. The arcuate path produces both a vertical rise component and a longitudinal translation component during transition between deployed and stowed configurations. In this manner, the longitudinal displacement of the distal end of the strut along the fore-aft axis exceeds a vertical displacement of the distal end along a vertical axis of the hull.

[0014] These and other aspects will become apparent from the following detailed description and the accompanying drawings.

[0015] In one aspect, a method of operating the watercraft includes transitioning the first and second arcuate struts from a stowed configuration to a deployed configuration by moving each arcuate strut along a respective arcuate path about a respective radial axis positioned outside an outer boundary of the flotation structure, each arcuate strut moving along a respective plane approximately parallel to one another. The method further includes securing the arcuate struts in the deployed configuration using respective adjustable fastening mechanisms and receiving a positive indication from a sensor on each fastening mechanism that the respective arcuate strut is fully locked; propelling the watercraft to a speed at or above a foiling threshold to generate hydrodynamic lift with the hydrofoil lift surfaces and elevate the flotation structure above a water surface; autonomously adjusting at least one active control surface based on signals from at least one height-above-water sensor and at least one inertial measurement unit to maintain a target ride height; and upon detection of a hazard condition by at least one underwater ultrasonic transducer, initiating a protective response comprising at least one of reducing thrust, adjusting the at least one active control surface to a neutral configuration, and transitioning at least one arcuate strut toward the stowed configuration.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016]

FIG. 1 shows a side view of the hydrofoil vehicle configured for operation in water with the first and second arcuate struts in the extended position. FIG. 2 presents a side view with the first and second arcuate struts retracted into the flotation structure. FIG. 3 shows a top view of the vehicle with the arcuate struts retracted into the flotation structure, illustrating the first flotation volume with a first cavity, and the second flotation volume with a second cavity.

FIG. 4 illustrates a side view with the second arcuate strut extended and the first arcuate strut shown transitioning between the extended and retracted positions. FIG. 5 illustrates a side view with the first arcuate strut extended and the second arcuate strut transitioning between the extended and retracted positions, illustrating the inner and outer radii.

FIG. 6 displays the distal portion of the first arcuate strut showing the hydrofoil, active control surface, actuator, and underwater sensor transducers including a forward-facing transducer and a downward-

facing transducer. FIG. 7 highlights the cavities within the flotation structure. FIG. 8 illustrates the first and second arcuate struts in a partially retracted configuration, showing a first strut coupling member pivotably coupled to the distal end of the first arcuate strut about a first pivot axis and a second strut coupling member pivotably coupled to the distal end of the second arcuate strut about a second pivot axis, with the respective hydrofoil lift surfaces and the change in angle of incidence of each foil during retraction.

DETAILED DESCRIPTION OF EMBODIMENTS

[0017] The following is intended to introduce the reader to the detailed description that follows and not to define or limit the claimed subject matter. Reference will now be made to various embodiments of the invention illustrated in the accompanying drawings. The described embodiments are provided for illustrative purposes and are not intended to limit the scope of the invention. As used throughout this specification, the terms "deployed configuration" and "extended position" are used interchangeably to describe the operational position of the hydrofoil struts; the terms "stowed configuration" and "retracted position" are used interchangeably to describe the stored position; the terms "hydrofoil lift surface," "hydrofoil," and "foil" are used interchangeably; and the terms "hydrofoil strut," "arcuate strut," and "strut" are used interchangeably.

Flotation Structure and Strut Configuration

[0018] FIG. 1 illustrates a side view of a vehicle 100 (also referred to herein as a watercraft) in accordance with a first embodiment of the invention configured for operation in a water medium 102, the vehicle having a bow 101b and a stern 101s, front and rear, or front and back, respectively. The vehicle 100 further includes a flotation structure 101 disposed between the bow 101b and the stern 101s. The vehicle includes a first arcuate strut 110 having a proximal end 110p movably coupled to the flotation structure 101 and a distal end 110d for being submerged in the water medium 102. The vehicle further includes a second arcuate strut 120 having a proximal end 120p movably coupled to the flotation structure 101 and a distal end 120d for being submerged in the water medium 102. The first arcuate strut 110 and the second arcuate strut 120 are configured to extend and retract relative to the flotation structure 101 in an arcuate manner. Each arcuate strut is operatively coupled to the flotation structure through a combination of pivot mounting hardware, guide tracks, and the adjustable fastening mechanism, such that the operative coupling permits rotational motion of each strut about the common radial axis 100c while transmitting structural loads during foiling operation and routing electrical signals for sensors and actuators.

[0019] The first and second arcuate struts 110, 120 each comprise an constant-radius inner radius 110i, 120i and an outer radius 110o, 120o that are approximately concentric and share an external approximately common radial axis 100c that is positioned outside an outer boundary of the flotation structure and generally below the vehicle. Because the radial axis is external to the flotation structure, it is positioned laterally outward relative to a vertical projection of the respective hydrofoil lift surface when the arcuate strut is in the deployed configuration. In the embodiment shown in FIG. 1, the first and second arcuate struts are shown extended from the flotation structure 101. As the arcuate struts extend or retract from the flotation structure 101, they move along the shared external approximately common radial axis 100c. In various embodiments, the inner radius of each arcuate strut may be between approximately 500mm and approximately 2000mm, and the outer radius may be between approximately 600mm and approximately 2200mm, depending on the size of the vehicle, the desired draft depth, and the target stowed profile. In one exemplary embodiment, the inner radius may be approximately 800mm and the outer radius may be approximately 960mm.

[0020] The arcuate retraction path enables the struts to sweep longitudinally within the hull envelope. In the deployed configuration, each arcuate strut extends below the flotation structure with the hydrofoil lift surface submerged. During retraction, the curved strut body traces an arcuate path that moves the lift surface both upward and longitudinally rearward, so the strut is progressively received within the strut cavity without requiring a vertical cavity depth equal to the deployed strut span. The stowed struts may be contained substantially within the outer envelope of the flotation structure. In certain embodiments, the first arcuate strut in the stowed configuration is received within both the first cavity and the second cavity, spanning across (that is, spans across) the boundary between the first and second flotation volumes.

[0021] The geometric advantage of the arcuate retraction path over a straight vertical retraction can be quantified trigonometrically. For a strut of radial thickness $t = R_{outer} - R_{inner}$ sweeping through angle θ, the arc length $s = R\theta$ determines the deployed span while the vertical rise $\Delta y = R(1-\cos\theta)$ determines the required cavity depth. Since the radial thickness is substantially less than the arc length, the vertical packaging depth is governed by the radial thickness independent of arc length, and is a fraction of the deployed span, for example less than about 50%, less than about 60%, or less than about 70% of the deployed usable strut span.

[0022] In certain embodiments, the angular range of the arcuate retraction path may be between approximately 60 degrees and approximately 120 degrees, and more preferably between approximately 80 degrees and approximately 100 degrees. The angular range determines the effective vertical reach of the deployed strut beneath the flotation structure as well as the length of the

stowed strut along the flotation structure. Larger angular ranges provide greater vertical reach for deeper draft operation, while smaller angular ranges result in shorter stowed profiles.

[0023] The one or more hydrofoil struts may occupy a stowed configuration for transport and storage, an intermediate transition configuration during deployment or retraction in which the strut is moving along the arcuate path, and a deployed configuration during hydrofoil operation in which the strut is locked in the extended position by the adjustable fastening mechanism. In certain embodiments, one or more intermediate partially retracted configurations may also be defined between the stowed and deployed configurations, as described further below.

[0024] More generally, each hydrofoil strut moves along a curved deployment path defined relative to the flotation structure during the transition between the deployed and stowed configurations, such that the distal end of each strut follows a non-linear trajectory. In the preferred embodiments described herein, this curved deployment path is an arcuate path about an external radial axis, but in other embodiments the curved deployment path may be produced by linkage mechanisms, cam-follower arrangements, or other mechanical configurations that cause the distal end to trace a curved trajectory rather than a straight-line during deployment and retraction.

[0025] The described arcuate retraction configuration allows the one or more hydrofoil struts to retract without requiring vertically extending hull cavities, thereby reducing overall vessel height during storage and transport. This compact stowed profile potentially enables the watercraft to be transported in the cargo area of a standard passenger vehicle, stored in a residential garage, and rolled through standard doorways, providing significant practical advantages for personal watercraft users.

Dual Flotation Volume and Steering Architecture

[0026] Referring to FIG. 1, the flotation structure 101 includes a first flotation volume 111 disposed proximate the bow and a second flotation volume 112 disposed approximately between the first flotation volume and the stern. The first flotation volume 111 is pivotably mounted to the second flotation volume 112 along a steering axis 100s. In various embodiments, the first flotation volume 111 may have a displacement of between approximately 15 liters and approximately 80 liters, and the second flotation volume 112 may have a displacement of between approximately 50 liters and approximately 200 liters, depending on the overall vehicle size and target payload capacity. In one exemplary embodiment, the first flotation volume may have a displacement of approximately 35 liters and the second flotation volume approximately 100 liters. The flotation structure 101 may be manufactured from composite material as well as foam so that it is rigid, light and preferably does not take on water ingress. Other manufacturing technologies are also envisaged as are known in the art, including but not limited to rotomolded polyethylene, fiberglass layup, vacuum-infused carbon fiber, hollow-core sandwich constructions, 3D-printed thermoplastic structures, or injection-molded polymer assemblies.

[0027] A battery compartment cavity (127) is housed within the second flotation volume (112) for storing a battery pack. The battery pack provides electrical energy to the propulsion unit (160) and control system (900). The second flotation volume (112) also houses the second cavity (112c) for receiving the second arcuate strut (120) in the stowed configuration.

Strut Cavities and Retraction Geometry

[0028] FIG. 3 illustrates a top view of the vehicle 100 with the first arcuate strut 110 and the second arcuate strut 120 retracted into the flotation structure 101. The first flotation volume 111 may have a first cavity 111c, and the second flotation volume 112 may have a second cavity 112c.

[0029] The first cavity 111c may be located towards the stern direction of the first flotation volume 111 where the first cavity 111c may further be located between the steering axis and the stern 101s end of the first flotation volume. There may be a gap between the first flotation volume and the second flotation volume 112. The second cavity 112c may be formed towards the stern end 101s of the steering axis 100s and the stern of the second flotation volume.

[0030] The first and second arcuate struts may be extended from the flotation structure 101 along first and second approximately parallel spaced-apart planes, 201, 202, where a first plane bisects 201 the first arcuate strut 110 and a second plane 202 bisects the second arcuate strut 120. The steering axis 100s may be located within the first plane 201 wherein the first arcuate strut 110 pivots about the steering axis 100s. In various embodiments, the steering axis 100s may have a rake of between approximately 5 degrees and approximately 25 degrees, and the first flotation volume may rotate between approximately plus or minus 10 degrees and approximately plus or minus 45 degrees about the steering axis. In one exemplary embodiment, the rake may be approximately 22 degrees and the rotation range approximately plus or minus 25 degrees.

[0031] The rake of the steering axis (100s), in combination with the mounting geometry of the first hydrofoil (151) at the distal end of the first arcuate strut (110), creates a caster effect similar to a bicycle fork. This provides self-centering stability during foiling operation and distributes steering forces across the hydrofoil lift surface.

Strut Transition and Hydrodynamic Alignment

[0032] FIG. 4 illustrates a side view of the vehicle 100 with the second arcuate strut 120 shown in the deployed configuration (extended position) from the flotation structure 101, while the first arcuate strut 110 is shown moving from the deployed configuration (extended position) 110e into the stowed configuration (retracted position) 110r. FIG. 5 illustrates the first arcuate strut 110 in the deployed configuration (extended position) while the second arcuate strut 120 transitions between the deployed configuration (extended position) 120e and the stowed configuration (retracted position) 120r, further illustrating the inner radius 110i, 120i and the outer radius 110o, 120o that are approximately concentric and share the external approximately common radial axis 100c.

Pitch-Axis Pivot Joint for Maintained Foil Orientation

[0033] Referring to FIG. 7, a first strut coupling member (856) is pivotably coupled to the distal end of the first arcuate strut (110) about a first pivot axis (851) defined by a pitch-axis pivot joint (850). A second strut coupling member (857) is similarly coupled to the second arcuate strut (120) about a second pivot axis. Each strut coupling member supports the respective hydrofoil lift surface and permits rotation about the pitch axis independently of the angular position of the arcuate strut, thereby decoupling foil orientation from strut retraction angle. The pitch-axis pivot joint permits the hydrofoil to maintain a hydrodynamic angle of attack (also referred to as an angle of incidence) within an operational range relative to oncoming flow during partial retraction of the strut.

[0034] In the fully deployed configuration, each strut coupling member (856, 857) is in a neutral position with the hydrofoil lift surface substantially horizontal. As the arcuate struts retract, each strut coupling member rotates about its respective pivot axis (851) to compensate for the changing strut angle, thereby maintaining the hydrofoil lift surface in a substantially horizontal orientation during partial retraction. This permits continued hydrodynamic lift generation during shallow-water foiling at reduced draft.

[0035] A pivot actuator (853) may actively control the rotation of each strut coupling member. A locking mechanism (854) may lock the foil in a fixed angular relationship with the strut when desired. The range of rotation may be limited to a predetermined angular range, for example between approximately minus 10 degrees and plus 45 degrees relative to horizontal. The propulsion unit (160) at the distal end of the second arcuate strut (120) also benefits from the pitch-axis pivot joint, maintaining thrust alignment during partial retraction.

[0036] In the fully stowed configuration, each strut coupling member (856, 857) may rotate to a maximum angular displacement, folding the hydrofoil lift surface and propulsion unit into alignment with the stowed arcuate strut to minimize the stowed profile within the flotation structure envelope.

Adjustable Fastening Mechanisms

[0037] Illustrated in FIG. 4 and FIG. 5 is a first adjustable fastening mechanism 141 disposed within the first cavity proximate the bow for adjustably clamping or holding the proximal end 110p of the first arcuate strut 110 in a fixed position relative to the first flotation volume 111 in the extended position. A second adjustable fastening mechanism 142 may be disposed within the second cavity proximate the stern for adjustably clamping or holding the proximal end 120p of the second arcuate strut 120 in a fixed position relative to the second flotation volume 112. In various embodiments, the arc length of each strut may be between approximately 500mm and approximately 3000mm, depending on the strut radius and angular range. In one exemplary embodiment, an inner arc length may be approximately 925mm and an outer arc length approximately 1100mm. Each adjustable fastening mechanism is configured to sustain operational hydrodynamic loads during foiling operation.

[0038] The first adjustable fastening mechanism (141) may clamp the strut from a leading and trailing edge using opposing clamp jaws actuated by a lever, cam, or motor-driven mechanism. A positive indication sensor such as a limit switch, Hall-effect sensor, or optical sensor detects when the clamp is fully engaged and communicates lock status to the control system (900).

[0039] The adjustable fastening mechanism may alternatively comprise a cam lock, toggle clamp, collet, or magnetic latch. Each adjustable fastening mechanism may include a manual override for emergency release of the arcuate strut.

Steering and Hydrofoil Lift Surfaces

[0040] As the first flotation volume rotates around the steering axis, the vehicle undergoes both pitch and roll movements. When the steering column is turned toward the starboard direction, the port-side control surface generates more lift than the starboard-side control surface, resulting in the vehicle pitching and rolling to the right, similar to motorcycle steering dynamics.

Active Control Surfaces and Actuators

[0041] FIG. 5 illustrates a side view of the distal portion 110d of the first arcuate strut 110 where the first hydrofoil 151 and the first actuator 151a and the first active control surface 151s are shown, wherein for increasing a lift of the first hydrofoil 151 the first active control surface 151s is moved away from a water surface 198. The first active control surface 151s may alternatively be moved towards the water surface 198 for decreasing lift.

[0042] The first actuator 151a may be in the form of an electromagnetic linear servo actuator. In other embodi-

ments, the actuator may be a rotary servo, a hydraulic actuator, a pneumatic actuator, or any other suitable actuation means. The active control surface may comprise a full-span flap, a trailing edge tab, an interceptor, a spoiler, or other control surface type known in the aerospace or marine arts.

[0043] A carriage mounting system comprising first and second carriages (171, 172) may be provided on the flotation structure to facilitate translational positioning of the arcuate struts along the flotation volumes.

Underwater Sensor Systems

[0044] Referring to FIG. 6, the first arcuate strut (110) includes at least a first transducer (801) oriented in a forward-facing direction and a second transducer (802) oriented in a downward-facing direction toward the water bottom. A third transducer (803) may be mounted on the second arcuate strut (120) oriented forward-facing. The transducers may comprise ultrasonic transducers operating in frequency ranges between approximately 50 kHz and 300 kHz, with forward-facing transducers operating at lower frequencies for longer range detection and downward-facing transducers at higher frequencies for higher resolution depth measurement.

[0045] The control system (900) processes echo returns from the forward-facing transducers (801, 803) to detect and classify submerged obstacles including rocks, debris, marine life, and other vessels. The downward-facing transducer (802) continuously measures water depth and compares it against minimum safe depth thresholds. Detection algorithms may include threshold-based detection, pattern recognition, and sensor fusion combining data from multiple transducers and other sensing modalities such as cameras or lidar to improve reliability and reduce false alarm rates.

[0046] When a hazard condition is detected, the control system (900) may initiate a graded protective response comprising at least one of: issuing a warning to the operator, reducing thrust, adjusting active control surfaces (151s, 152s) to a neutral configuration, and transitioning at least one arcuate strut from the deployed configuration toward the stowed configuration to reduce draft and exposure to the detected hazard.

Hazard Detection and Automatic Retraction

[0047] In certain embodiments, the control system may be configured to initiate automatic retraction of the hydrofoil struts in response to one or more hazard conditions. Hazard conditions triggering automatic retraction may include: detection of shallow water or a submerged obstacle within a predetermined distance by the forward-facing or downward-facing sensors; loss of rider contact as detected by a pressure sensor, capacitive sensor, or dead-man switch on the flotation structure; vehicle speed dropping below a minimum foiling threshold for a predetermined duration; loss of communication with one or more critical sensors or actuators; or activation of a manual emergency retraction switch by the rider. The automatic retraction may be performed at a controlled rate to minimize hydrodynamic forces during the retraction motion, or may be performed rapidly in emergency situations where rider safety takes priority over structural considerations.

Propulsion System

[0048] An ESC 166 is coupled with the battery and the BLDC motor 161 and is configured to receive a control signal from a control circuit which may include an IMU 169. High current wires 810w connect to the battery compartment connector and other low current signal and voltage wires 811w propagate to the linear actuator and other below water electronic and electromechanical components disposed within or connected with the arcuate struts. A water thruster mechanism 160 enclosed within the housing 163 is generally safer than an exposed propeller.

[0049] Thrust vectoring may enhance maneuverability by aligning the rear propulsion system with the turning arc of the front flotation volume. As the front flotation volume pivots along the steering axis, rear thrust vectoring adjusts accordingly, allowing the vehicle to execute smooth, controlled banking turns. The propulsion unit may include a thrust vectoring nozzle for directional control of the water jet output.

[0050] A handlebar assembly (180) may be mounted to the flotation structure for operator control, providing throttle, braking, and steering inputs. The watercraft may support multiple riding modes including standing, seated, and prone configurations.

[0051] A control system (900) comprising one or more processors receives input from sensors including an inertial measurement unit (169), height-above-water sensors (333), and ultrasonic transducers (801, 802, 803), and commands actuators for active control surfaces, thrust, and strut deployment.

[0052] The control system (900) may manage multiple operational states including idle, displacement cruising, foiling transition, active foiling, descent, and emergency modes, with automatic transitions between states based on sensor inputs and speed thresholds.

Shallow-Water Foiling and Docking Mode

[0053] In shallow-water foiling mode, the arcuate struts may be partially retracted to reduce draft while maintaining hydrodynamic lift, with the pitch-axis pivot joints permitting the hydrofoil lift surfaces to maintain a substantially horizontal orientation at intermediate strut angles. A docking mode may fully retract the struts and limit propulsion output for safe maneuvering in confined waterways.

[0054] The control system may automatically deploy or retract the arcuate struts based on watercraft speed relative to a foiling threshold, transitioning between dis-

placement and foiling configurations without operator intervention.

[0055] The control system may enforce geofencing boundaries using GPS position data, automatically reducing speed or retracting the struts when the watercraft approaches or exceeds a predefined operational boundary.

[0056] The watercraft may be configured for autonomous operation including GPS waypoint-following navigation, return-to-base functionality, and obstacle avoidance using sensor fusion from the ultrasonic transducers and GPS receivers.

[0057] A payload mounting interface may be provided on the flotation structure for unmanned cargo delivery operations, with the control system managing autonomous navigation, payload monitoring, and return-to-base sequences.

[0058] The arcuate struts may be formed from carbon fiber, fiberglass, aluminum, or composite materials, and may include hydrodynamic fairing profiles to reduce drag. The hydrofoil lift surfaces may incorporate symmetric or cambered foil profiles optimized for the intended speed range.

[0059] The arcuate struts may be removably coupled to the flotation structure via a modular interface comprising alignment features and quick-release fasteners, permitting field replacement or interchange of struts having different lengths, curvatures, or foil configurations.

Compact Transport and Storage

[0060] Advantageously, the extendable and retractable strut mechanism is beneficial for both compact storage and safety. When fully extended, the struts and hydrofoils significantly increase the vehicle's footprint, making storage cumbersome. In the collapsed position, the vehicle may be small enough to be stored within the trunk of an SUV, eliminating the need for a trailer.

[0061] In the stowed configuration, each hydrofoil strut is positioned substantially within a vertical projection of the flotation structure, such that the struts do not extend laterally beyond an outer lateral envelope defined by the widest point of the flotation structure. This means that the overall width and lateral profile of the watercraft in the stowed configuration is determined by the flotation structure alone, not by protruding strut or foil elements. The arcuate retraction path achieves this compact stowed envelope because the struts sweep longitudinally along the hull rather than folding laterally outward. Stated differently, in the stowed configuration, each arcuate strut is contained substantially within the outer envelope of the flotation structure such that no portion of the arcuate strut extends laterally beyond an outer lateral boundary of the flotation structure, and the watercraft in the stowed configuration has a transverse width permitting passage through a standard residential doorway.

[0062] A width of the vehicle in the stowed configuration allows it to be rolled through common doors as are found in a house. In some embodiments, the width of the vehicle in the stowed configuration may be approximately 900mm or less, permitting passage through a standard residential doorway. In some embodiments, the width may be further alterable with some structures having hinged or sliding elements to further reduce width. The height of the vehicle in the stowed configuration permits transport in the cargo area of a standard passenger vehicle such as an SUV, station wagon, or pickup truck, without requiring a trailer or roof rack.

[0063] A set of wheels 129 (FIG. 1), may be positioned near the battery compartment as part of the second flotation volume to facilitate ground movement or rolling of the vehicle when the arcuate struts are in the retracted position. In some embodiments, the wheels may be retractable, foldable, or removable to reduce drag and improve hydrodynamic performance during water operation.

Height Control and Ride Dynamics

[0064] A height-sensing mechanism 333 may be mounted on either the first or second flotation volume to measure the vehicle's height above the water surface 922. Through a feedback control loop utilizing an inertial measurement unit (IMU) and height above water surface sensors, the control system may autonomously adjust pitch to maintain a predetermined ride height. Preferably the vehicle's operational ride height 922 as measured from the lower part of the second flotation volume can be adjusted between 5cm and 30cm above the water surface 198.

[0065] In use when the vehicle is operating with maximum height above the water surface, the water surface line may be in an approximately same plane as the external approximately common radial axis. In various embodiments, the vehicle 100 may have a total mass of between approximately 30 kg and approximately 120 kg including the battery, and may support rider weights of between approximately 40 kg and approximately 150 kg.

[0066] Approximately 20% of the arcuate struts as measured from the distal ends should remain submerged in the water during foiling operation, preventing excessive lift and potential capsizing.

[0067] In operation, the watercraft transitions from displacement mode to foiling mode as forward speed increases, with the control system autonomously adjusting active control surfaces to maintain a target ride height and attitude. The operator controls speed and direction via the handlebar assembly while the control system manages foil dynamics.

[0068] For night and low-visibility operation, the watercraft may include navigation lights, reflective markings, and enhanced sensor processing for the ultrasonic transducers to maintain hazard detection capability.

Alternative Embodiments

[0069] Alternative embodiments may include variations in the number, arrangement, and geometry of arcuate struts, flotation volumes, and hydrofoil lift surfaces. The retraction mechanism may employ hydraulic, pneumatic, electric, or manual actuation. The flotation structure may be configured as a monohull, catamaran, trimaran, or other multi-hull arrangement while retaining the arcuate strut retraction geometry described herein.

[0070] The flotation structure and strut cavities may be manufactured using composite layup, rotational molding, thermoforming, or CNC-machined tooling, with dimensional tolerances selected to ensure proper clearance for strut retraction along the arcuate path.

[0071] The electric propulsion system and foiling operation reduce acoustic emissions and wake generation compared to conventional planing hulls, making the watercraft suitable for noise-sensitive and environmentally protected waterways.

[0072] The first and second arcuate struts may be actuated independently or synchronously by respective pivot actuators (853). The strut geometry and actuation may be symmetric about a longitudinal centerline of the flotation structure, though asymmetric configurations are also contemplated.

[0073] Control policies for the control system (900) may be developed or refined using simulation-based training, including reinforcement learning within a physics-based simulation environment with domain randomization. Trained policies may be exported and deployed to the physical watercraft.

Geometric Packaging Advantage of Arcuate Retraction

[0074] In certain embodiments, each retractable lift structure is supported by a curved or arcuate strut that rotates about a pivot axis positioned outside the flotation structure of the watercraft. Retraction of the lift structure therefore occurs along an arcuate path rather than along a purely linear or vertical path.

[0075] The arcuate motion of the strut may be approximated as a circular sweep defined by a radius R and an angular displacement θ. The corresponding kinematic path length of a point along the strut may be approximated by the relationship: $s = R\theta$, where s represents the theoretical arc length traveled during the retraction motion. The motion also produces both a vertical displacement and a longitudinal displacement of the lift structure relative to the watercraft. For a circular sweep, the approximate vertical rise Δy and longitudinal translation Δx may be expressed as: $\Delta y = R(1-\cos\theta)$ and $\Delta x = R \sin\theta$.

[0076] Accordingly, the retraction motion distributes the recovery of the deployed support span between vertical displacement and longitudinal sweep. This contrasts with a straight vertical retraction mechanism, in which the vertical travel distance would generally be comparable to the deployed usable span of the strut or lift-support structure.

[0077] In the present system, the arcuate retraction path allows a relatively large deployed support span to be recovered with a substantially smaller vertical packaging requirement because the retraction motion includes a significant longitudinal component. As a result, the vertical packaging depth required to store the lift structure within the watercraft may be materially less than the deployed usable span of the strut.

[0078] By way of non-limiting example, an embodiment may include a curved strut having inner and outer radii on the order of approximately 817 mm and 956 mm respectively, and rotating through an angular sweep of approximately 55 degrees. For such an embodiment, the theoretical arc path of portions of the strut may be on the order of several hundred millimeters to nearly one meter depending on the radial position. The vertical rise associated with the sweep may be substantially smaller than the recovered path length because the motion also produces significant longitudinal translation.

[0079] In certain implementations, a deployed usable strut span of approximately 720 mm may be stowed with a vertical packaging depth on the order of approximately 337 mm. Thus, the required vertical storage depth may be reduced by approximately half relative to a comparable straight vertical retraction path recovering the same deployed span. These values are provided for illustrative purposes and may vary depending on specific geometry, sweep angle, and packaging configuration.

[0080] In some embodiments, the housing of the watercraft is configured to receive at least a portion of the retracting lift structure such that the resulting packaged configuration occupies a vertical depth that is less than the deployed usable span of the strut. In certain embodiments the packaged vertical depth may be less than about 70%, less than about 60%, or less than about 50% of the deployed usable strut span. The reduction in vertical packaging depth allows the lift structures to be stowed within the outer envelope of the flotation structure, thereby improving storage, transport, and shallow-water operation of the watercraft.

[0081] In alternative embodiments, the retractable strut need not itself be arcuate. A substantially straight strut may be guided along a curved guide path defined by a guide structure such as a curved track, curved rail, curved slot, or linkage mechanism coupled to the flotation structure. In such embodiments, the guide structure constrains the strut to follow a curved trajectory between the deployed and stowed configurations, producing both vertical displacement and longitudinal displacement of the hydrofoil lift surface relative to the flotation structure, even though the strut body itself is not curved. The curved guide path may be defined by one or more of: a curved channel formed in the flotation structure, a set of linkage arms that constrain the strut to a non-linear path, or a cam-and-follower arrangement in which a follower on the strut rides along a curved cam surface. Regardless of the specific guide mechanism, the resulting retraction motion

produces the same geometric packaging advantage as an arcuate strut: the lift structure sweeps longitudinally during retraction, reducing the vertical cavity depth required to stow the strut within the flotation structure. The longitudinal displacement may exceed the vertical displacement during the retraction motion.

Claims

1. A watercraft comprising: a hull (101); a hydrofoil (151, 152) configured to generate hydrodynamic lift when submerged; a hydrofoil strut (110, 120) coupled to the hull and supporting the hydrofoil at a distal end thereof, the hydrofoil strut being movable between a deployed position in which the hydrofoil is positioned beneath the hull to generate hydrodynamic lift, and a retracted position in which the hydrofoil strut is at least partially received within or against the hull; **characterized in that** a guide structure constrains the hydrofoil strut to move along a curved path relative to the hull, and wherein movement of the hydrofoil strut along the curved path changes both the vertical and longitudinal position of the hydrofoil relative to the hull.

2. A method of operating a hydrofoil watercraft having a hull (101) and a hydrofoil strut (110, 120) supporting a hydrofoil (151, 152), the method comprising: transitioning the hydrofoil strut from a stowed configuration to a deployed configuration by moving the hydrofoil strut along a curved path relative to the hull, the curved path producing both vertical displacement and longitudinal displacement of the hydrofoil relative to the hull; generating hydrodynamic lift with the hydrofoil in the deployed configuration; **characterized in that** transitioning the hydrofoil strut from the deployed configuration to the stowed configuration comprises moving the hydrofoil strut along the curved path such that the hydrofoil strut is received within or against the hull in the stowed configuration, the longitudinal displacement of the hydrofoil during said transitioning exceeding the vertical displacement.

3. The watercraft of claim 1, wherein the hydrofoil strut is an arcuate strut (110, 120) and the curved path is an arcuate path about a radial axis (100c) positioned outside an outer boundary of the hull (101).

4. The watercraft of claim 3, wherein the arcuate path is a constant-radius path, and wherein a vertical depth of a cavity (111c, 112c) within the hull required to receive the arcuate strut (110, 120) in the retracted position is governed by a radial thickness of the arcuate strut, the radial thickness being defined as a difference between an outer radius and an inner radius of the constant-radius path, such that the vertical depth of the cavity is substantially independent of an arc length of the arcuate strut measured along the constant-radius path.

5. The watercraft of claim 3, wherein during transition of the arcuate strut (110, 120) between the deployed position and the retracted position, a longitudinal displacement of the distal end of the arcuate strut along a fore-aft axis of the hull (101) exceeds a vertical displacement of the distal end of the arcuate strut along a vertical axis of the hull.

6. The watercraft of claim 1, wherein in the retracted position the hydrofoil strut (110, 120) and the hydrofoil (151, 152) are stowed substantially within an outer envelope of the hull (101) such that no portion of the hydrofoil strut extends laterally beyond an outer lateral boundary of the hull.

7. The watercraft of claim 6, wherein the watercraft in the retracted position has a transverse width permitting passage through a standard residential doorway.

8. The watercraft of claim 1, further comprising a pitch-axis pivot joint (850) rotatably coupling the hydrofoil (151, 152) to the distal end of the hydrofoil strut (110, 120), the pitch-axis pivot joint (850) defining a pivot axis oriented substantially parallel to a lateral axis of the watercraft.

9. The watercraft of claim 8, wherein the pitch-axis pivot joint (850) permits the hydrofoil (151, 152) to rotate relative to the hydrofoil strut (110, 120) so as to maintain a hydrodynamic angle of attack within an operational range when the hydrofoil strut is in an intermediate partially retracted position between the deployed and retracted positions.

10. The watercraft of claim 1, further comprising at least one active control surface (151s, 152s) on the hydrofoil (151, 152), the active control surface being deflectable by a respective actuator to regulate hydrodynamic lift.

11. The watercraft of claim 10, further comprising a controller (900) configured to independently command the active control surface (151s, 152s) to control at least pitch of the watercraft during foiling operation.

12. The watercraft of claim 11, further comprising a height-above-water sensor (333) mounted on the hull (101) and configured to measure a distance between the hull and a water surface, wherein the controller (900) is configured to command the active control surface (151s, 152s) to maintain a target ride height based on signals from the height-above-water

sensor.

13. The watercraft of claim 1, wherein the hull (101) comprises a first flotation volume (111) having a first cavity (111c) and a second flotation volume (112) having a second cavity (112c), the watercraft further comprising a first arcuate strut (110) movable along a first arcuate path and a second arcuate strut (120) movable along a second arcuate path, the first and second arcuate paths being approximately concentric about a common radial axis (100c) external to the hull, and wherein in the retracted position the first arcuate strut (110) spans across a boundary between the first cavity (111c) and the second cavity (112c).

14. The watercraft of claim 13, wherein the first arcuate strut (110) moves along a first plane (201) and the second arcuate strut (120) moves along a second plane (202), the first and second planes being parallel spaced-apart planes.

15. The watercraft of claim 1, further comprising at least one adjustable fastening mechanism (141, 142) configured to releasably secure the hydrofoil strut (110, 120) in the deployed position and to sustain operational hydrodynamic loads during foiling operation, and a propulsion unit (160) coupled to the hydrofoil strut and including a thrust vectoring nozzle (164) configured to selectively redirect a thrust vector to provide directional control forces.

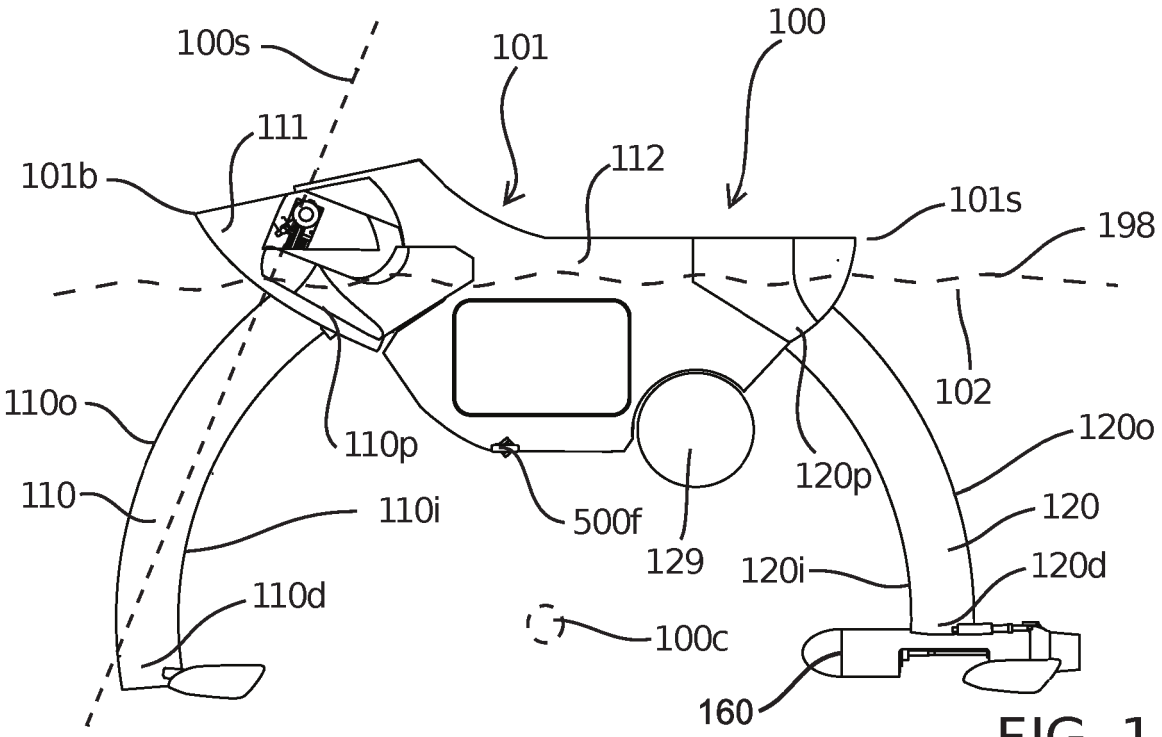

100s
101
100
111
112
101b
101s
198
102
110o
110p
120o
110
110i
500f
120p
120
129
120i
120d
110d
100c
160

FIG. 1

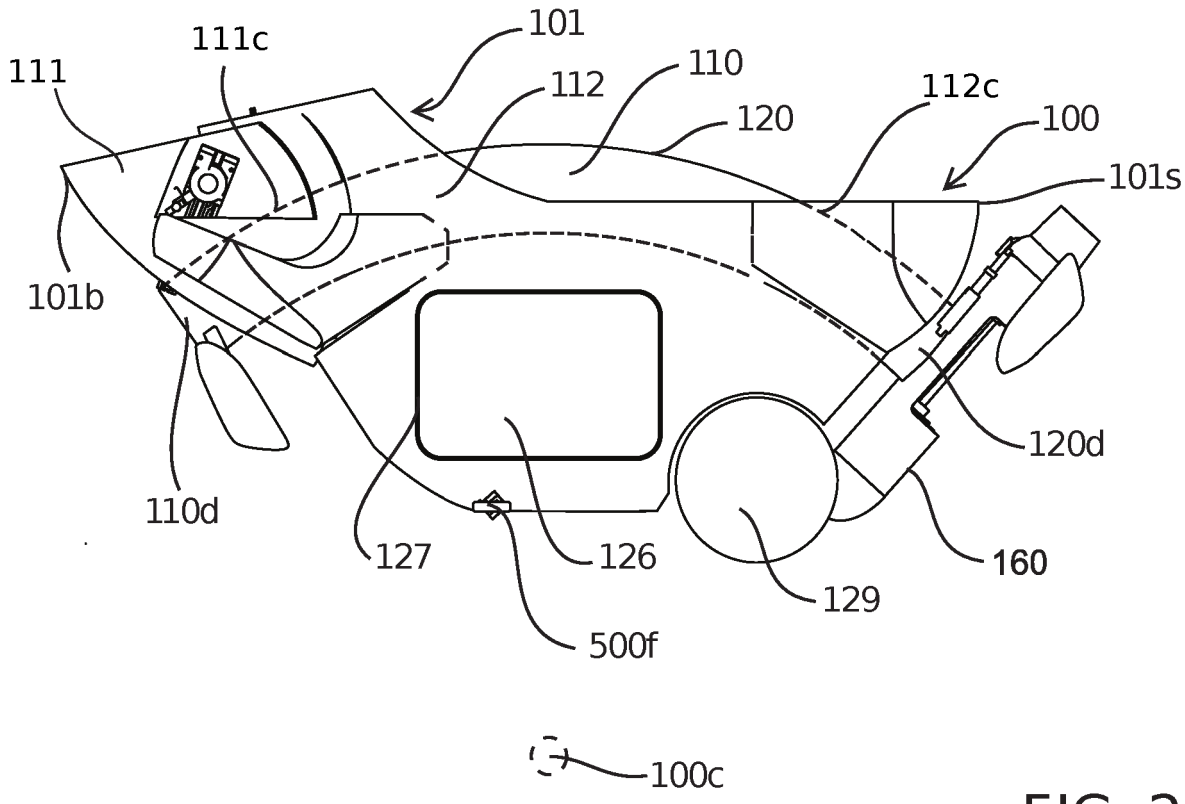

101
111c
111
112
110
112c
120
100
101s
101b
120d
110d
127
126
160
129
500f
100c

FIG. 2

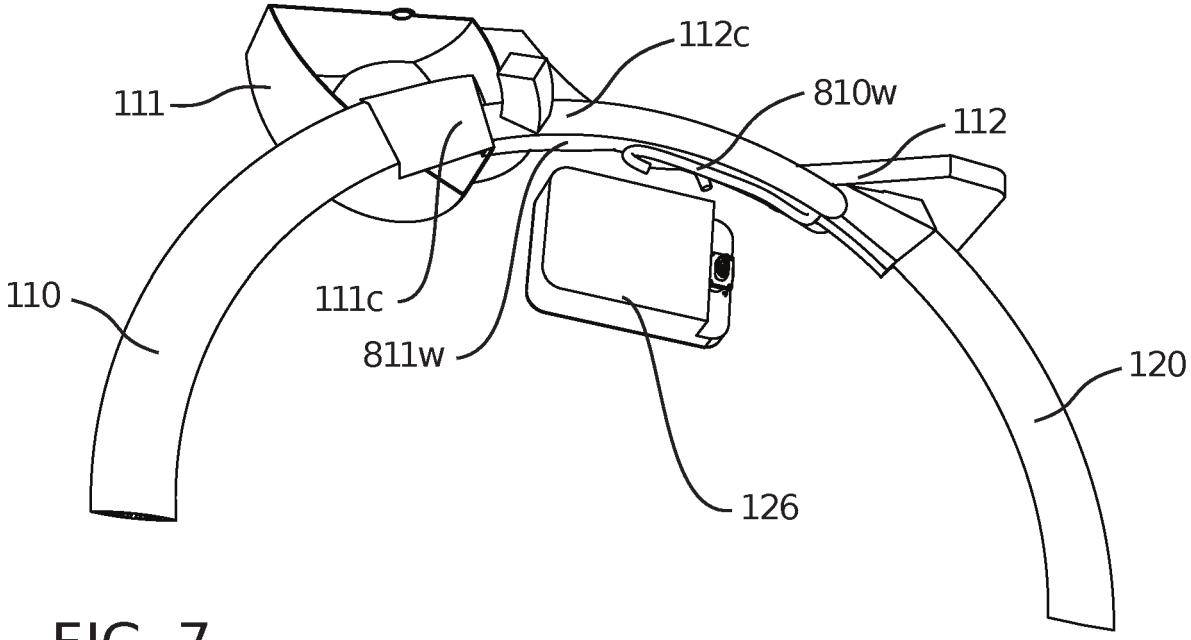
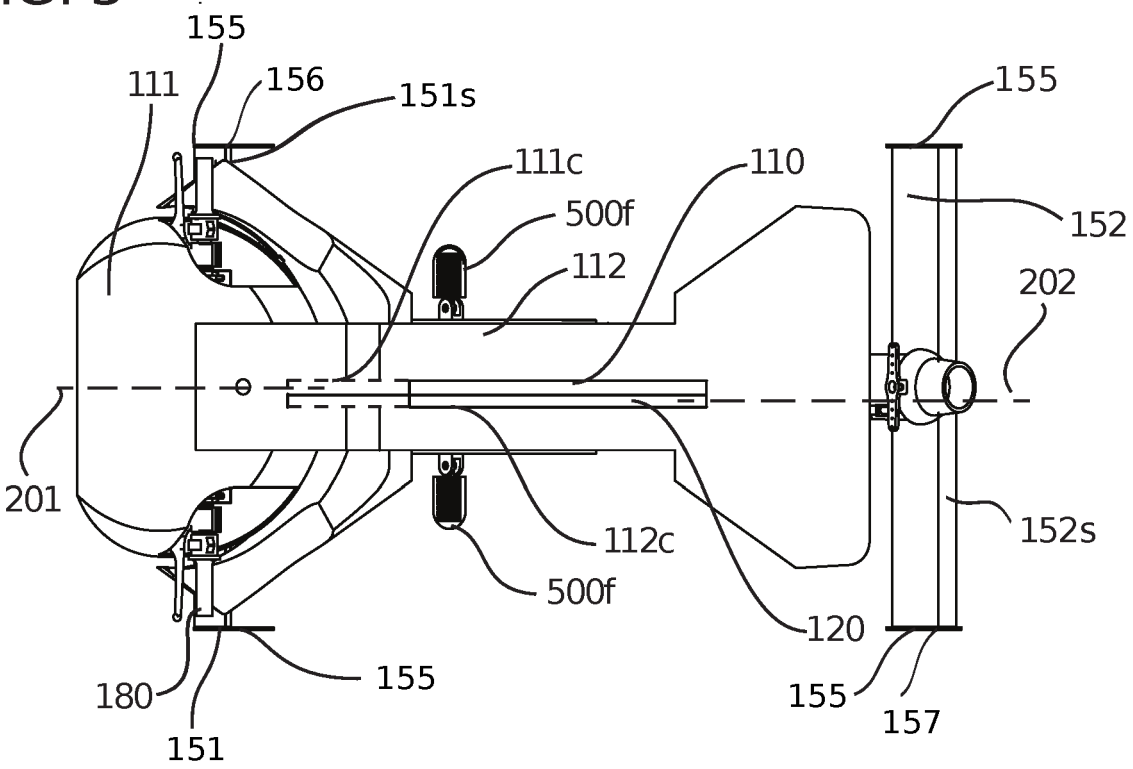

112c
111
810w
112
110
111c
811w
120
126

FIG. 7

FIG. 3


155
111
156
151s
111c
110
155
500f
152
112
202
201
112c
152s
500f
120
180
155
155
151
157

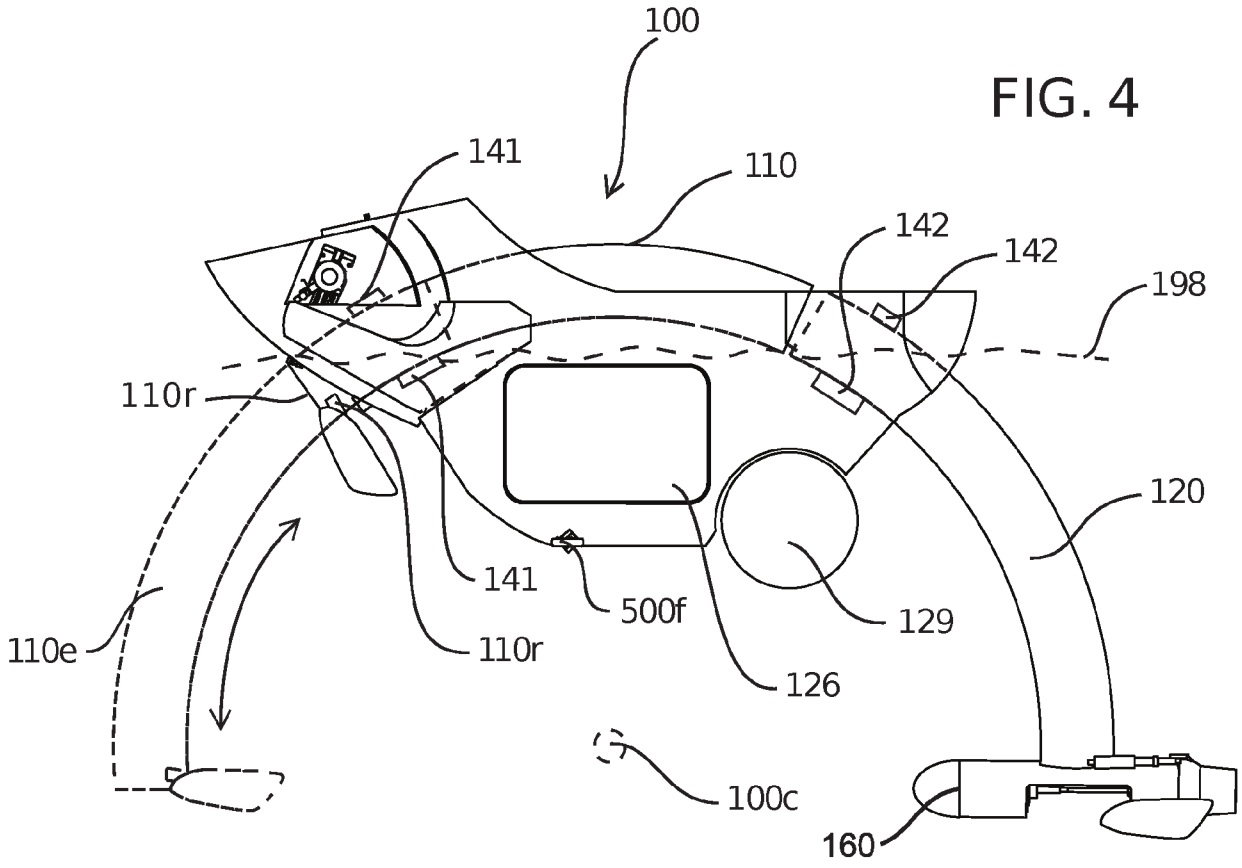

100
141
110
142
142
198
110r
120
141
500f
129
110e
110r
126
100c
160

FIG. 4

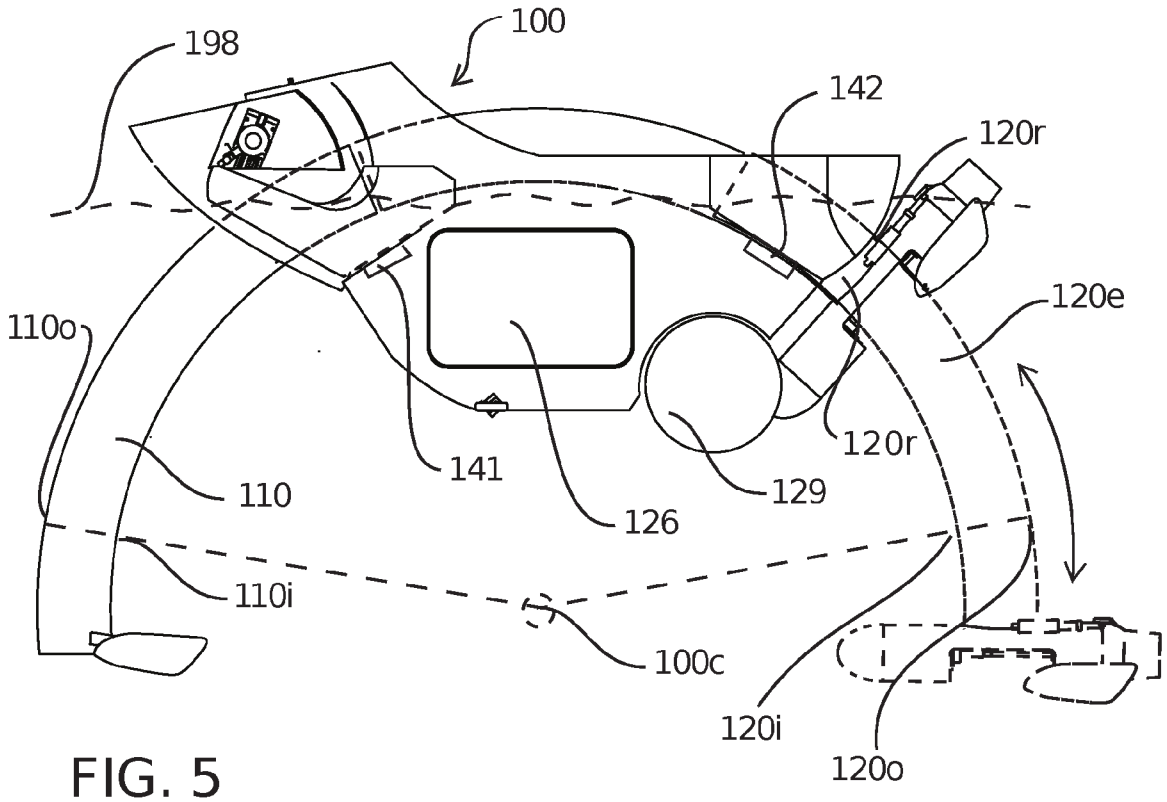

198
100
142
120r
120e
110o
120r
141
129
110
126
110i
100c
120i
120o

FIG. 5

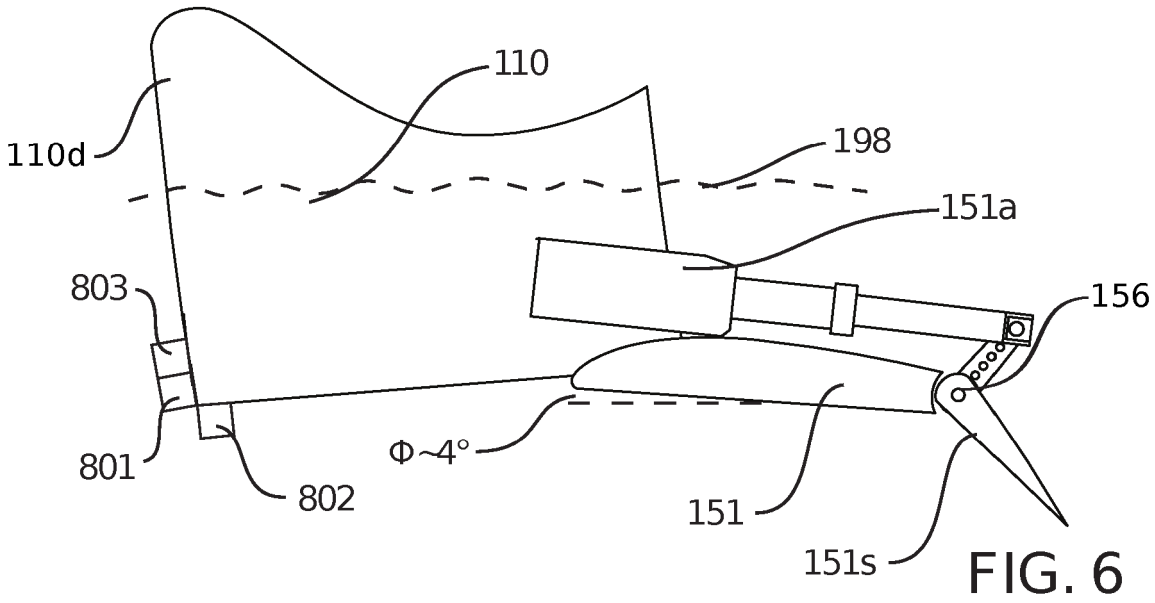

110
110d
198
151a
803
156
801
802
Φ~4°
151
151s

FIG. 6

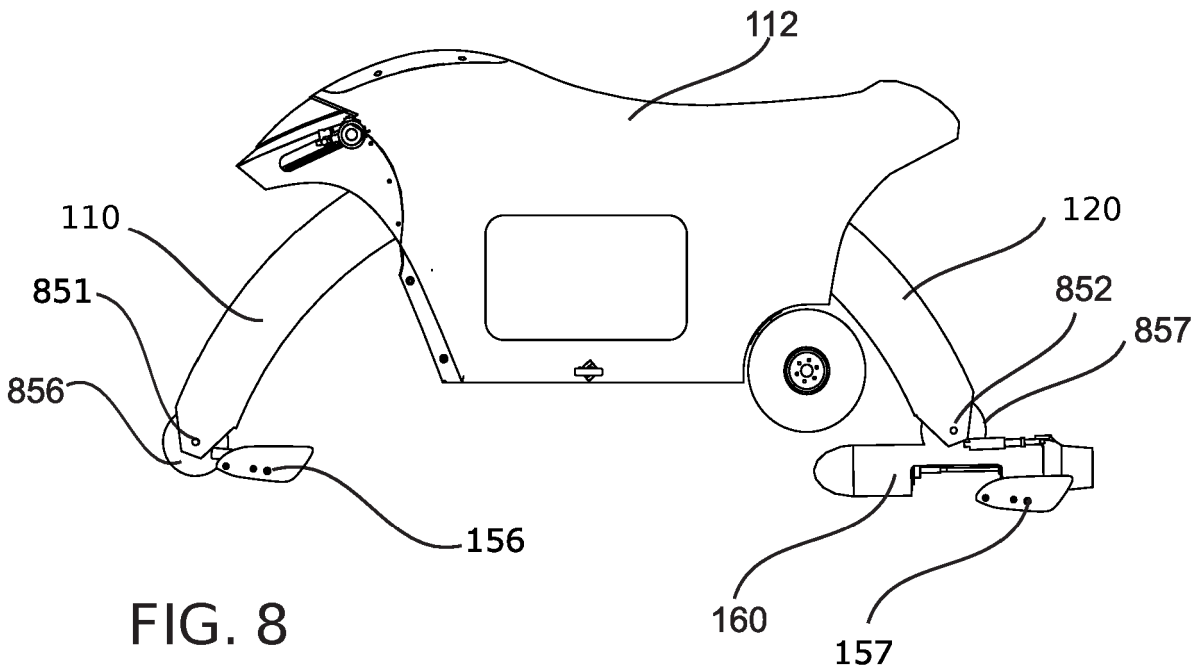

112
110
120
851
852
857
856
156
160
157

FIG. 8

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EUROPEAN SEARCH REPORT

Application Number
EP 26 16 5243

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	EP 4 361 013 A1 (BREDOHL WILLI [DE])	1,3,4,7,	INV.
	1 May 2024 (2024-05-01)	13-15	B63B1/30
Y	* paragraphs [0014], [0020]; figures 1-5 *	5	B63B1/24
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X	US 5 653 189 A (PAYNE PETER R [US])	1,2,6,	B63B32/64
	5 August 1997 (1997-08-05)	8-12	B63B34/10
Y	* figures 17, 6, 7, 8, 16a-16c *	5	B63B34/40

TECHNICAL FIELDS SEARCHED (IPC)

B63B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	24 August 2026	Ibarrondo, Borja

CATEGORY OF CITED DOCUMENTS

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EPO FORM 1503 03.82 (P04C01)

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24-08-2026

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

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