

SENSOR CONFIGURATION OF CRAFT

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Prov. App. 63/550,428 titled “Sensor Configuration of Craft,” filed on Feb. 6, 2024, and currently pending. The entire contents of U.S. Prov. App. 63/550,428 are incorporated herein by reference.

[0002] This application also incorporates by reference the entire contents of: (i) U.S. Prov. App. 63/493,575, titled “Water Landing of Airborne Craft with Hydrofoil,” filed Mar. 31, 2023, and now expired; (ii) Int’l App. PCT/US2023/029996, titled “Hydrofoil Takeoff and Landing With Multiple Hydrofoils,” filed Aug. 10, 2023, and published as WO 2024/035885 on Feb. 15, 2024, as; (iii) U.S. App. 17/875,942, titled “Determining Characteristics of a Water Surface Beneath a Vehicle in Motion,” filed Jul. 28, 2022, published as U.S. Pub. 2022/0382300 on Dec. 1, 2022, and currently pending; (iv) U.S. Prov. App. 63/459,201, titled “Providing Feedback on a Mode Transition of a Craft,” filed Apr. 13, 2023, and now expired; (v) U.S. Prov. App. 63/547,191, titled “Hydrofoil Retraction System,” filed Nov. 3, 2023, and now expired.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] The accompanying drawings are included to provide a further understanding of the claims, are incorporated in, and constitute a part of this specification. The detailed description and illustrated examples described serve to explain the principles defined by the claims.

[0004] Figures 1A-1D illustrate various views of a craft, in accordance with example embodiments.

[0005] Figure 2 illustrates a main hydrofoil deployment system of a craft, in accordance with example embodiments.

[0006] Figure 3 illustrates a rear hydrofoil deployment system of a craft, in accordance with example embodiments.

[0007] Figure 4 illustrates a battery system of a craft, in accordance with example embodiments.

[0008] Figure 5 illustrates a control system of a craft, in accordance with example embodiments.

[0009] Figure 6A illustrates a craft in a hull-borne mode of operation, in accordance with example embodiments.

- [0010] Figure 6B illustrates a craft in a hydrofoil-borne maneuvering mode of operation, in accordance with example embodiments.
- [0011] Figure 7A illustrates a craft in a hydrofoil-borne takeoff mode of operation, in accordance with example embodiments.
- [0012] Figure 7B is a graph that illustrates various lift forces acting on a craft, in accordance with example embodiments.
- [0013] Figure 8 illustrates a craft in a wing-borne mode of operation, in accordance with example embodiments.
- [0014] Figures 9A and 9B illustrate altitude sensors that facilitate sensing the altitude of a craft, in accordance with example embodiments.
- [0015] Figure 10 illustrates object detection sensors placed on various positions of a craft, in accordance with example embodiments.
- [0016] Figure 11 illustrates sensors that facilitate below-water object sensing, in accordance with example embodiments.
- [0017] Figure 12 illustrates sensors that facilitate monitoring operations performed by a craft, in accordance with example embodiments.
- [0018] Figure 13 illustrates conflict detection and resolution control (CDRC) logic implemented a control system, in accordance with example embodiments.
- [0019] Figure 14 illustrates a graphical representation of a conflict risk map, in accordance with example embodiments.
- [0020] Figure 15 illustrates various obstacle avoidance operations performed by a craft, in accordance with example embodiments.
- [0021] Figure 16 illustrates various surface-piercing object identification operations performed by a craft, in accordance with example embodiments.

DETAILED DESCRIPTION

[0022] Various examples of systems, devices, and/or methods are described herein. Any embodiment, implementation, and/or feature described herein as being an “example” is not necessarily to be construed as preferred or advantageous over any other embodiment, implementation, and/or feature unless stated as such. Thus, other embodiments, implementations,

and/or features may be utilized, and other changes may be made without departing from the scope of the subject matter presented herein.

[0023] Accordingly, the examples described herein are not meant to be limiting. It will be readily understood that the aspects of the present disclosure, as generally described herein, and illustrated in the figures, can be arranged, substituted, combined, separated, and designed in a wide variety of different configurations.

[0024] Further, unless the context suggests otherwise, the features illustrated in each of the figures may be used in combination with one another. Thus, the figures should be generally viewed as component aspects of one or more overall embodiments, with the understanding that not all illustrated features are necessary for each embodiment.

[0025] Additionally, any enumeration of elements, blocks, or steps in this specification or the claims is for purposes of clarity. Thus, such enumeration should not be interpreted to require or imply that these elements, blocks, or steps adhere to a particular arrangement or are carried out in a particular order.

[0026] Further, terms such as “A coupled to B” or “A is mechanically coupled to B” do not require members A and B to be directly coupled to one another. It is understood that various intermediate members may be utilized to “couple” members A and B together.

[0027] Moreover, terms such as “substantially” or “about” that may be used herein, are meant that the recited characteristic, parameter, or value need not be achieved exactly but that deviations or variations, including, for example, tolerances, measurement error, measurement accuracy limitations and other factors known to skill in the art, may occur in amounts that do not preclude the effect the characteristic was intended to provide.

I. Introduction

[0028] Aspects described herein are generally related to craft, such as aircraft, including craft that are capable of taking off from, and landing on, water. Examples of such craft include crafts having extendible hydrofoils attached to the hull of the craft. For instance, a first (or “rear”) hydrofoil may be positioned towards the tail section of the craft, and a second (or “main”) hydrofoil may be positioned near the midsection of the craft, forward the first hydrofoil (e.g., proximate to the main wing of the craft). The hydrofoils may be controlled to extend and retract depending on the operating mode of the craft. For example, when airborne, the hydrofoils may

be retracted towards the hull, and when hull-borne or foil-borne, the hydrofoils may be extended. The term “hull” is used throughout this description to refer to the main body of the craft. It is understood that this term is interchangeable with the term “fuselage,” among other possible terms, which is sometimes used to refer to the main body of aircraft.

[0029] In some examples, the craft may additionally or alternatively be a wing-in-ground (WIG) effect craft. Such craft fly close to the ground or water surface by using the ground effect principle, where flying close to the surface reduces aerodynamic drag and increases lift. For example, the drag on the craft is reduced when its distance from the ground is within about the length of the aircraft’s wingspan.

[0030] Some examples of craft disclosed herein are operated at times in relatively congested environments. For example, there may be other craft operating on waterways used by the craft, such as large ships, recreational watercraft, or other wing-in-ground craft. In addition, there may be partially submerged or completely submerged objects in the water that could collide with the hydrofoils of the craft, or other portions of the craft, when the craft is hydrofoil borne. The presence of these other craft and objects increases the risk of collision not only when the craft is traveling in the water but also when the craft is airborne because the craft flies relatively close to the water’s surface.

[0031] To address these and other issues, some examples of craft disclosed herein include various systems/sensors configured to sense/detect such craft and objects. In this regard, facilitating both on-water operations (e.g., hull-borne and hydrofoil-borne operations) and airborne operations of these craft may, in some examples, necessitate a) using different types of sensors and/or combinations of sensors during different respective modes of operation and b) strategically positioning the sensors on different positions of the craft in such a way as to facilitate both above-water object sensing and below-water object sensing.

[0032] Some examples of the craft also include sensors that facilitate determining the position and orientation of the craft and monitoring the performance of some systems/components of the craft.

[0033] In some examples, sensor data from these systems/sensors is communicated to a control system of the craft, and the control system fuses the sensor data together to obtain insight into the environment in which the craft is or will be operating along with the state of the craft. This insight, in turn, is used by the control system to, for example, help control (either

automatically or in combination with operator input) operations performed by the craft and assess the risk of the craft coming dangerously close to any sensed/detected objects within the environment.

[0034] In some examples, the risk assessment is based in part on factors such as a) the current trajectory of the craft, b) the craft's intended path, c) the positions and trajectories of objects detected in the environment, and d) whether the objects are or will be within a threshold distance from points along the craft's trajectory or path. In some examples, the risk assessment is further based on the type/size of the objects. For example, the control system may assess/predict large ships to move slower and less erratically than smaller recreational craft. In some examples, the fused-together sensor information from above-water object detection sensors and below-water object detection sensors allows the control system to identify surface-piercing objects such as icebergs, buoys, partially submerged containers, logs, etc. The control system may assess/predict these types of objects to be relatively stationary or slow-moving. The control system may assess/predict other surface-piercing objects, such as swimmers, breaching whales, dolphins, etc., to move somewhat erratically.

[0035] Some examples of the control system convey the risk assessment to the pilot via a pilot-control user interface. For example, the pilot-control user interface may indicate the relative position and trajectory of objects near the craft along with an indication of the current trajectory and/or intended path of the craft. The pilot-control user interface may alert the pilot to those objects that pose the greatest risk of collision. Some examples of the control system also convey via the pilot-control user interface one or more flight paths/plans that are optimized to mitigate/minimize the risk of collision. In some examples, the pilot may, via the pilot-control user interface, select a particular flight path/plan, and the control system may communicate information to a vehicle control system (VCS) of the craft to cause the craft to travel/operate according to a selected flight path/plan. The VCS, in turn, controls systems of the craft to cause the craft to, for example, change direction, altitude, speed, etc., as needed. In some examples, the control system may automatically (e.g., without pilot input) cause the craft to travel/operate according to a particular flight path/plan.

[0036] Some examples of WIG craft that can be configured to perform the operations described above are described below. These craft include retractable hydrofoils that are extended during takeoff to generate additional upward lift as the craft approaches take-off speeds. The

upward lift raises the hull of the craft above the water. This action i) reduces the wetted surface area of the craft and, therefore, drag on the craft and ii) allows the craft to cruise through rough waters during takeoff without colliding with waves. Once airborne, the hydrofoils may be retracted. Some examples of these craft include and implement features disclosed in U.S. Patent Application No. 17/570,090, filed January 6, 2022 (herein after '090 application), and U.S. Patent Application No. 17/845,480, filed June 21, 2022 (herein after '480 application). The '090 and '480 applications are incorporated herein by reference in their entirety. The '090 application describes, among other things, a seaglider that includes a pair of retractable hydrofoils (e.g., main and rear hydrofoils) that facilitate hydrofoil-borne operation of the craft. The '480 application describes, among other things, a seaglider that implements a bi-plane tail.

[0037] Other examples of craft to which the aspects described herein can be applied correspond to blown wing craft. In these craft, air is blown over the wings of the craft by propellers, and the blowing of the air over the wings contributes meaningfully to the overall lift acting on the craft. Examples of these craft can include 4, 5, 6, or even more propellers on each wing. Some examples of the WIG craft described herein are blown wing craft. Some of these craft include six propellers on each wing, making these craft better suited for commercial travel.

[0038] These and other aspects are discussed in more detail in the passages that follow.

II. Example Wing-In-Ground Effect Vehicles

[0039] Figures 1A-1D illustrate different views of an example of a craft 100. As shown, some examples of the craft 100 include a hull 102, a main wing 104, a tail 106, a main hydrofoil assembly 108, and a rear hydrofoil assembly 110.

A. Hull

[0040] Some examples of the craft 100 operate in a first waterborne mode for an extended period of time, during which the hull 102 is at least partially submerged in water. As such, some examples of the hull 102 are configured to be watertight, particularly for surfaces of the hull that contact the water during this first waterborne operational mode. Further, some examples of the hull 102, as well as the entirety of the craft 100, are configured to be passively stable on all axes when floating in water. To help achieve this, some examples of the hull 102 include a keel (or centerline) 112, which provides improved stability and other benefits described below. Some examples of the craft 100 include various mechanisms for adjusting the center of mass of the

craft 100 so that the center of mass aligns with the center of buoyancy of the craft 100. For instance, in some examples, a battery system (described in further detail below in connection with Figure 4) of the craft 100 is electrically coupled to one or more moveable mounts. Some examples of the mounts are moved by one or more servo motors or the like. In some examples, a control system of the craft 100 is configured to detect a change in its center of buoyancy, for instance, by detecting a rotational change via an onboard gyroscope, and responsively operate the servo motors to move the battery system until the gyroscope indicates that the craft 100 has stabilized. Some examples of the craft 100 include a ballast system for pumping water or air to various tanks distributed throughout the hull 102 of the craft 100. The ballast system facilitates adjusting the center of mass of the craft 100 so that the center of mass aligns with the center of buoyancy of the craft 100. Other example systems may be used to control the center of mass of the craft 100 as well.

[0041] Additionally, or alternatively, some examples of the hull 102 are configured to reduce drag forces when both waterborne and wing-borne. For instance, some examples of the hull 102 have a high length-to-beam ratio (e.g., greater than or equal to 8), which facilitates reducing hydrodynamic drag forces when the craft 100 is under forward waterborne motion. Some examples of the keel 112 are curved or rockered to improve maneuverability when waterborne. Further, some examples of the hull 102 are configured to pierce the surface of waves (e.g., to increase passenger and crew comfort) by including a narrow, low-buoyancy bow portion of the hull 102.

B. Wing and Distributed Propulsion System

[0042] As shown in Figures 1A-1D, some examples of the main wing 104 include an outrigger 114 at each end of the main wing 104. The outriggers 114 (which are sometimes referred to as “wing-tip pontoons”) are configured to provide a buoyant force to the main wing 104 when submerged or when otherwise in contact with the water, which improves the stability of the craft 100 during waterborne operation. Some examples of the outriggers 114 may also include integrated pumps (e.g., propeller pumps) that facilitate providing thrust in some scenarios, as described in more detail below.

[0043] As shown in Figure 1D, some examples of the main wing 104 have a gull-wing shape such that the outriggers 114 at the ends of the main wing 104 are at the lowest point of the main

wing 104 and are positioned approximately level with (or slightly above) a waterline of the hull 102 when the hull 102 is waterborne.

[0044] Some examples of the main wing 104 have a high aspect ratio, which is defined as the ratio of the span of the main wing 104 to the mean chord of the main wing 104. In some examples, the aspect ratio of the main wing 104 is greater than or equal to five, or greater than or equal to six, but other example aspect ratios are possible as well. Such wings tend to have reduced pitch stability and maneuverability due to lower roll angular acceleration. These issues are ameliorated by various mechanisms described below. On the other hand, such wings tend to have increased roll stability and increased efficiency resulting from higher lift-to-drag ratios. Further, high aspect ratio wings provide a longer leading edge for the mounting of a distributed propulsion system along the wing.

[0045] As shown in the figures, some examples of the main wing 104 include a number of electric motor propeller assemblies 116 distributed across a leading edge of the main wing 104. This arrangement corresponds to a blown-wing propulsion system. Arranging the propeller assemblies 116 in this manner increases the speed of air moving over the main wing 104, which increases the lift generated by the main wing 104. This increase in lift allows the craft 100 to take off and become wing-borne at slower vehicle speeds. This facilitates, for example, taking off on water which can be difficult at higher speeds due to the various forces that would otherwise act on the craft 100.

[0046] The electric motor propeller assemblies 116 tend to be much lighter, less complex, and smaller than the liquid-fueled engines used on conventional craft. Some examples of the electric motor propeller assemblies 116 are controlled by an electronic speed controller and powered by an onboard battery system (e.g., a lithium-ion system, magnesium-ion system, lithium-sulfur system, etc.). Some examples of the electric motor propeller assemblies 116 are controlled by a fuel cell or a centralized liquid-fueled electricity generator. In some examples, the onboard electrical supply system includes multiple systems for supplying power during different operational modes, such as a first battery system configured to deliver large amounts of power during takeoff and a second system with a higher energy density but lower peak power capability for delivering sustained lower power during cruise operation (e.g., during hydrofoil waterborne operation or during wing-borne operation, each of which are described in further detail below).

[0047] In some examples, the positioning of the electric motor propeller assemblies 116 along the leading edge of the main wing 104 is determined based on a variety of factors including, but not limited to, (i) the total thrust for all modes of operation of the craft 100, (ii) the thrust generated by each individual propeller of the propeller assemblies 116, (iii) the radius of each propeller in the respective propeller assemblies 116, (iv) the tip clearance between each propeller and the surface of the water, and (v) the additional freestream speed over the main wing 104 required for operation.

[0048] As shown in the figures, in some examples, the number of propeller assemblies 116 is symmetrical across both sides of the hull 102. In some examples, the propeller assemblies 116 are identical. In some examples, the propeller assemblies 116 have different propeller radii or blade configurations along the span so long as the configuration is symmetrical across the hull 102. The different radii facilitate adequate propeller tip clearance from the water or vehicle structure. In some examples, the different propellers are optimized for different operational conditions, such as wing-borne cruise. The propeller placement and configuration may vary to increase the airflow over the main wing 104 or tail system 106 to improve controllability or stability. While eight total propeller assemblies 116 are illustrated, the actual number of propeller assemblies 116 can vary based on the requirements of the craft 100.

[0049] In some examples, the propeller assemblies 116 have different pitch settings or variable pitch capabilities based on their position on the main wing 104. For instance, in some examples, a subset of the propeller assemblies 116 have fixed-pitch propellers sized for cruise speeds, while the remainder of the propeller assemblies 116 have fixed-pitch propellers configured for takeoff or can allow for varying the propeller's pitch.

[0050] In some examples, different propeller assemblies 116 are turned off or have reduced rotational speeds during different modes of operation. For instance, during waterborne operation, one or more of the propeller assemblies 116 may be turned off or have reduced rotational speeds in a manner that generates asymmetrical thrust. This may create a yawing moment on the craft 100, allowing the craft 100 to turn without large bank angles and increasing the turning maneuverability of the craft 100. For instance, in order to yaw right, the craft 100 may increase the rotational speeds of the propellers of one or more of propeller assemblies 116g-l while decreasing the rotational speeds of the propellers of one or more of propeller assemblies 116a-f. Similarly, to yaw left, the craft 100 may increase the rotational speeds of the propellers of one or

more of propeller assemblies 116a-f while decreasing the rotational speeds of the propellers of one or more of propeller assemblies 116g-l.

[0051] Similarly varying rotational speeds or propeller pitches may be used to yaw or roll the aircraft in flight or while foiling due to varied forces and lift distributions imposed over the wing and its control surfaces or in general used to tailor the lift distribution across the wing for optimized efficiency.

[0052] In some examples, the propeller assemblies may tilt to vector thrust either to provide directly more vertical lift or to change how the wing is blown depending on the mode of operation so as to tailor the blown lift distribution.

[0053] Some examples of the main wing 104 include one or more aerodynamic control surfaces, such as flaps 118 and ailerons 120. Some examples of these controls comprise movable hinged surfaces on the trailing or leading edges of the main wing 104 for changing the aerodynamic shape of the main wing 104. Some examples of the flaps 118 are configured to extend downward below the main wing 104 to reduce stall speed and create additional lift at low airspeeds, while some examples of the ailerons 120 are configured to extend upward above the main wing 104 to decrease lift on one side of the main wing 104 and induce a roll moment in the craft 100. In some examples, the ailerons 120 are additionally configured to extend downward below the main wing 104 in a flaperon configuration to help the flaps 118 generate additional lift on the main wing 104, which, in some examples, is used to either create a rolling moment or additional balanced lift depending on coordinated movement of both ailerons. Some examples of the flaps 118 and ailerons 120 include one or more actuators for raising and lowering the flaps 118 and ailerons 120. Within examples, the flaps 118 include one or more of plain flaps, split flaps, slotted flaps, Fowler flaps, slotted Fowler flaps, Gouge flaps, Junkers flaps, or Zap flaps. Further, in some examples, the flaps 118 (and the ailerons 120 when configured as flaperons) are positioned to be in the wake of one or more of the propeller assemblies 116. In some examples, the ailerons 120 are positioned so that they are in the wake of one or more of the propeller assemblies 116 to increase the effectiveness of the ailerons at low forward velocities. Some of the propeller assemblies 116 are positioned so that no ailerons 120 are in their wake to increase thrust on the outboard wing during a turn without inducing adverse yaw. For example, in a left turn, a normal airplane would have adverse yaw to the right as the right aileron is deflected down, increasing drag. In the present disclosure, however, the right propeller assembly outboard

of the right aileron may have its thrust increased relative to the respective left propeller assembly, initiating a turn without adverse yaw.

C. Tail System

[0054] As illustrated in Figures 1A-1D, some examples of the tail 106 include a vertical stabilizer 122, a horizontal stabilizer 124, and one or more control surfaces, such as elevators 126. Similar to the flaps 118 and ailerons 120, some examples of the elevators 126 comprise movable hinged surfaces on the trailing or leading edges of the horizontal stabilizer 124 for changing the aerodynamic shape of the horizontal stabilizer 124 to control a pitch of the craft 100. Some examples of the horizontal stabilizer 124 are combined with the elevator 126, creating a fully articulating horizontal stabilizer (e.g., a stabilator). Raising the elevator 126 above the hinge point creates a net downward force on the tail system and causes the craft 100 to pitch upward. Lowering the elevators 126 below the hinge point creates a net upward force on the horizontal stabilizer 124 and causes the craft 100 to pitch downward. Some examples of the elevators 126 include actuators, which are operated by a control system of the craft 100 to raise and lower the elevators 126.

[0055] As illustrated in Figures 1A-1D, some examples of tail 106 include a rudder 128. Some examples of the rudder 128 comprise a movable hinged surface on the trailing edge of the vertical stabilizer 122 for changing the aerodynamic shape of the vertical stabilizer 122 to control the yaw of the craft 100 when operating in an airborne mode. In some examples, the rudder 128 additionally changes a hydrodynamic shape of the hull 102 to control the yaw of the craft 100 when operating in a waterborne mode. To facilitate such hydrodynamic control, in some examples, the rudder 128 is positioned low enough on the tail 106 that the rudder 128 is partially or entirely submerged when the hull 102 is floating in water. For instance, the rudder 128 is positioned partially or entirely below the waterline of the hull 102. Some examples of the rudder 128 include one or more actuators, which are operated by a control system of the craft 100 to rotate the hinged surface of the rudder 128 to the left or right of the vertical stabilizer 122. Actuating the rudder 128 to the left (relative to the direction of travel) causes the craft 100 to yaw left. Actuating the rudder 128 to the right (relative to the direction of travel) causes the craft 100 to yaw right. As such, the rudder 128 may be used in combination with any of the other mechanisms disclosed herein for controlling the yaw of the craft 100, including in combination

with the ailerons 120 during airborne operation and in combination with varying the rotational speeds of different ones of the propeller assemblies 116 to help improve the maneuverability of the craft 100 during waterborne operation.

[0056] Some examples of the tail 106 include one or more vertical stabilizers 122a, 122b, 122n, one or more horizontal stabilizers 124a, 124b, one or more control surfaces, such as elevators 126, and one or more tail flaps 127 for enhanced pitch control configured to exert enhanced net downward force on the tail system. It should be understood that although the figures show only two horizontal stabilizers, it is contemplated that more than two of each can be used within the scope of the present teachings. In some applications, it has been found that the transition from waterborne operation to airborne or wing-borne operation can require a larger pitching moment to overcome the larger drag forces existing between the hull 102 and/or the hydrofoil assemblies 108, 110 and the water. This phenomenon can further occur in wheeled aircraft configured for short takeoff and landing (STOL) operations. In this way, at low airspeeds, aerodynamic forces in conventional designs fail to produce sufficient downward force to permit sufficient pitching moment. To provide sufficient pitching moment to pitch the craft 100 upward, a conventional solution would be to increase the span of the tail so that the elevator generates more force; however, a resultant consequence of increasing the span of the tail is that the entire tail must be stronger and heavier, which can result in undesired reduction of payload and efficiency. However, the present configuration provides improved performance by providing a tail 106 having a first horizontal stabilizer 124a and a second horizontal stabilizer 124b. It should be understood that one or more additional horizontal stabilizers can be used.

[0057] In some examples, a first horizontal stabilizer 124a is a lower horizontal stabilizer relative to a second horizontal stabilizer 124b. However, it should be appreciated that the horizontal stabilizers in some examples can be interchanged for performance purposes (e.g., the disclosed structure of the first horizontal stabilizer 124a can be incorporated in the upper horizontal stabilizer and the disclosed structure of the second horizontal stabilizer 124b can be incorporated in the lower horizontal stabilizer). In some non-limiting examples, the structure, shape, and/or performance of each horizontal stabilizer can be tailored as desired such that the lower horizontal stabilizer (in this example, the first horizontal stabilizer 124a) is more likely to experience aerodynamic effect from being in the wake of the blown-wing propulsion system disclosed herein or associated wake produced by alternative propulsion systems. In this way,

greater aerodynamic control and/or downwards lift can be generated during desired phases of operation.

[0058] Some examples of the horizontal stabilizers 124a, 124b include one or more aerodynamic control surfaces, such as tail flaps 127 and elevators 126, which may comprise movable hinged surfaces on the trailing or leading edges of the horizontal stabilizer 124a, 124b for changing the aerodynamic shape of the respective horizontal stabilizer 124a, 124b. It should be recognized that at least one of the horizontal stabilizers 124a, 124b can be sized, shaped, and/or spaced relative to a second of the horizontal stabilizers 124a, 124b to enhance or minimize the aerodynamic effect on the adjacent stabilizers. In this way, the aerodynamic flow, pressures, and/or forces can be used to improve the efficiency or effectiveness of the adjacent stabilizer. In some examples, at least one of the horizontal stabilizers 124a, 124b can be actuated in an opposing direction. In some embodiments, at least one of the horizontal stabilizers 124a, 124b can define a ratio of a surface area of the first horizontal stabilizer to a surface area of the second horizontal stabilizer in the range of 0.9 to 1.6. In some non-limiting example configurations, the surface area of the first horizontal stabilizer is 5.7 m², the surface area of the second horizontal stabilizer is 3.9 m², both have a chord of about 1 m and a vertical separation of 1.8 m. In some embodiments, a vertical separation distance between the first horizontal stabilizer and the second horizontal stabilizer is in the range of 0.25 to 0.75 of the lower horizontal stabilizer span. In some examples, a vertical separation distance can be dependent on the required rudder authority and thus elevator size (driven by, e.g., yaw stability, or the need to counteract asymmetric thrust following powerplant failure). In some examples, a sweep offset moves the center of pressure further aft from the center of gravity, thus allowing the airfoil of the horizontal stabilizer to have less surface area overall, thus being smaller and lighter. In some examples, a dihedral in the bottom surface of the horizontal stabilizer adds stability. In some examples, the box tail design itself increases the efficiency due to the elimination of wingtip vortices of a typical tail. In some embodiments, a lower horizontal stabilizer may have approximately a 15% thickness-to-chord ratio to support the weight of the upper components, whereas the vertical and upper surfaces may be thinner, such as, for example, 10% thickness-to-chord ratio due to reduced structural load requirement, which enables the upper horizontal stabilizer to be more efficient (lower drag). It should be appreciated that the left and right elevator surfaces 126 can be controlled independently and/or differentially to create a rolling

moment, thereby enabling the wing ailerons 120 to be made smaller. The smaller wing ailerons 120 further enable larger flaps 118. It should be appreciated that in some embodiments, using the vertical control surfaces 128a, 128b, 128n can change the pressure distribution across the elevator 126, for example, commanding a left 5 degree deflection in the left vertical control surface may move the mean pressure distribution left/right by a percentage of the elevator width.

[0059] Some examples of the tail flaps 127 are configured to selectively extend upward above the horizontal stabilizer 124 for changing a surface area, camber, aspect ratio, and/or shape of the horizontal stabilizer 124. The tail flaps 127 may include, for example, one or more of plain flaps, split flaps, slotted flaps, Fowler flaps, slotted or double-slotted Fowler flaps, Gouge flaps, Junkers flaps, or Zap flaps. That is, in some examples, tail flaps 127 serve to change an angle of attack of the horizontal stabilizer 124, change a chord line of the horizontal stabilizer 124, change a surface area of the horizontal stabilizer 124, and/or otherwise increase the net effective downwardly directed lift of the horizontal stabilizer 124. Such configurations effectively reduce the speed at which the horizontal stabilizer 124 becomes aerodynamically effective by creating additional net downward force at low airspeeds to aid in exerting a nose-up pitching moment of the craft 100. The elevators 126 may be configured for changing the aerodynamic shape of the horizontal stabilizer 124 to further control or vary a pitch of the craft 100.

[0060] In some examples operations, the tail flaps 127 are deployed for takeoff (e.g., transition from hydrofoil-borne mode to airborne mode) and landing (e.g., transition from airborne mode to hull-borne mode) to generate additional downforce on the tail system when additional pitch-up moment is required. Tail flaps 127 can be stowed for other phases of operation, such as hull-borne mode, to reduce downforce on the tail system and reduce drag.

[0061] In some examples, the elevators 126 are additionally configured to extend upward above the horizontal stabilizer 124 in a flaperon-like configuration (yet with elevators, rather than ailerons) to help the tail flaps 127 generate additional downward force on the horizontal stabilizer 124, which may be used to either create a pitching moment or additional balanced downward force. The tail flaps 127 and elevators 126 may each include one or more actuators 125 for raising and lowering the tail flaps 127 and elevators 126, singly or in combination. The actuators 125 can comprise any system configured to selectively actuate the associated system, such as but not limited to a flap track system (integrated into vertical stabilizers 122a, 122b, 122n, which can reduce complex hinge systems or external arms, thereby reducing wetted area

and excrescences drag), an electric servo motor mounting within the vertical stabilizers 122a, 122b, 122n and/or horizontal stabilizers 124a, 124b, and/or a central vertical strut system generally mounted in the hull 102 or the fuselage of the craft 100 (to provide the potential for reduced cross-sectional area and associated drag).

[0062] Further, in some examples, the elevators 126 and/or the tail flaps 127 are positioned so that they are in the wake 129 of one or more of the propeller assemblies 116 of main wing 104. The elevators 126 and/or the tail flaps 127 may be positioned so that they are in the wake 129 of one or more of the propeller assemblies 116 to increase the effectiveness of the elevators at low forward velocities. In some examples, the propeller assemblies 116 are positioned so that no elevators 126 and/or tail flaps 127 are in the wake 129 to ensure consistent and/or predictable aerodynamic forces, independent of power application, are exerted during critical operational phases. In some examples, the propeller assemblies 116 are positioned so that the elevators 126 are in their wake 129 and the tail flaps 127 are not in the wake 129 (e.g., above the wake 129) and are exposed to clean air 131. It should be understood that positioning of the tail flaps 127 in the second horizontal stabilizer 124b, or at a distance above the center of gravity of the craft 100, will have the added unexpected benefit of creating additional nose-up pitching moment as a result of induced drag acting about the center of gravity causing the craft 100 to pitch upward.

[0063] Similar to the flaps 118 and the ailerons 120 of the main wing 104, some examples of the elevators 126 comprise movable hinged surfaces on the trailing or leading edges of the horizontal stabilizer 124 for changing the aerodynamic shape of the horizontal stabilizer 124 to control a pitch of the craft 100. The horizontal stabilizer 124 may be combined with the elevator 126, creating a fully articulating horizontal stabilizer (e.g., a stabilator). Raising the elevators 126 above the hinge point creates a net downward force on the tail system and causes the craft 100 to pitch upward. Lowering the elevators 126 below the hinge point creates a net upward force on the horizontal stabilizer 124 and causes the craft 100 to pitch downward. The elevators 126 may include actuators, which may be operated by a control system of the craft 100 in order to raise and lower the elevators 126.

[0064] In some examples, the tail 106 includes one or more rudders 128a, 128b, 128n. The rudders 128a, 128b, 128n may each comprise a movable hinged surface on the trailing edge of the corresponding vertical stabilizers 122a, 122b, 122n for changing the aerodynamic shape of the vertical stabilizer 122 to control the yaw of the craft 100 when operating in an airborne mode.

It should be understood that rudders 128a, 128b, 128n can operate independently or in combination as desired. Moreover, in some examples, rudders 128a, 128b, 128n can be used as redundant systems, particularly useful in the event of one or more failures.

[0065] In some examples, the rudders 128a, 128b, 128n additionally change a hydrodynamic shape of the hull 102 to control the yaw of the craft 100 when operating in a waterborne mode. In order to facilitate such hydrodynamic control, the rudders 128a, 128b, 128n may be positioned low enough on the tail 106 that one or more of the rudders 128a, 128b, 128n is partially or entirely submerged when the hull 102 is floating in water. Namely, the rudders 128a, 128b, 128n may be positioned partially or entirely below a waterline of the hull 102. The rudders 128a, 128b, 128n may include one or more actuators, which may be operated by a control system of the craft 100 in order to rotate the hinged surface of the rudders 128a, 128b, 128n to the left or right of the vertical stabilizer 122. Actuating the rudders 128a, 128b, 128n to the left (relative to the direction of travel) causes the craft 100 to yaw left. Actuating the rudders 128a, 128b, 128n to the right (relative to the direction of travel) causes the craft 100 to yaw right. As such, the rudders 128a, 128b, 128n may be used in combination with any of the other mechanisms disclosed herein for controlling the yaw of the craft 100, including in combination with the ailerons 120 during airborne operation and in combination with varying the rotational speeds of different ones of the propeller assemblies 116 to help improve the maneuverability of the craft 100 during waterborne operation.

[0066] It should be understood that the fundamental shape of tail 106, having one or more vertical stabilizers 122a, 122b, 122n and one or more horizontal stabilizers 124a, 124b, can result in a box-like assembly, wherein the vertical stabilizers are generally coupled to the horizontal stabilizers to form a reinforced box-like construction. This box-like construction provides enhanced structural integrity that enables tail 106 of some examples to be lighter and/or smaller than otherwise constructed.

[0067] Some examples of the craft 100 include a distributed propulsion system on the tail 106, which may be similar to the distributed propulsion system of propeller assemblies 116 on the main wing 104. Such a distributed propulsion system may provide similar benefits of increasing the freestream velocity over the control surfaces (e.g., the elevators 126 and/or the rudder 128) to allow for increased pitch and yaw control of the craft 100 at lower travel speeds. When determining the number and size of propeller assemblies to include on the tail 106, one

may apply the same factors described above when determining the number and size of propeller assemblies to include on the main wing 104.

D. Hydrofoil Systems

[0068] As noted above, some examples of the craft 100 include a main hydrofoil assembly 108 and a rear hydrofoil assembly 110. In some examples, the main hydrofoil assembly 108 is positioned proximate to the middle or bow of the craft 100, and the rear hydrofoil assembly 110 is positioned proximate to the stern. For instance, some examples of the main hydrofoil assembly 108 is positioned between the bow and a midpoint (between the bow and stern) of the craft 100, and some examples of the rear hydrofoil assembly 110 is positioned below the tail 106 of the craft 100.

[0069] The main hydrofoil assembly 108 and the rear hydrofoil assembly 110 are configured to facilitate the breaking of contact between the hull of the craft and the water surface during takeoff, which, as noted above, can otherwise be challenging in some conventional craft designs. Some examples of the main hydrofoil assembly 108 and the rear hydrofoil assembly 110 are configured to be retractable, large enough to lift the entire craft out of the water and not impact the water surface, and to enable sustained operation in the hydrofoil-borne mode (where the entire weight of the craft is supported by the one or more hydrofoil assemblies).

[0070] Some examples of the main hydrofoil assembly 108 include a main hydrofoil 130, one or more main hydrofoil struts 132 that couple the main hydrofoil 130 to the hull 102, and one or more main hydrofoil control surfaces 134. Similarly, some examples of the rear hydrofoil assembly 110 include a rear hydrofoil 136, one or more rear hydrofoil struts 138 that couple the rear hydrofoil 136 to the hull 102, and one or more rear hydrofoil control surfaces 140.

[0071] Some examples of the main hydrofoil 130 and the rear hydrofoil 136 take the form of one or more hydrodynamic lifting surfaces (also referred to as “foils”) configured to be operated partially or entirely submerged underwater while the hull 102 of the craft 100 remains above and clear of the water’s surface. In operation, as the craft 100 moves through water with the main hydrofoil 130 and the rear hydrofoil 136 submerged, the hydrofoils generate a lifting force that causes the hull 102 to rise above the surface of the water. In general, the lifting force generated by the hydrofoils must be at least equal to the weight of the craft 100 to cause the hull 102 to rise above the surface of the water. The lifting force of the hydrofoils depends on the speed and angle

of attack at which the hydrofoils move through the water, as well as their various physical dimensions, including the aspect ratio, the surface area, the span, and the chord of the foils.

[0072] The height at which the hull 102 is elevated above the surface of the water during hydrofoil-borne operation is limited by the length of the one or more main hydrofoil struts 132 that couple the main hydrofoil 130 to the hull 102 and the length of the one or more rear hydrofoil struts 138 that couple the rear hydrofoil 136 to the hull 102. In some examples, the main hydrofoil strut 132 and the rear hydrofoil strut 138 are long enough to lift the hull 102 at least five feet above the surface of the water during hydrofoil-borne operation, which facilitates operation in substantially choppy waters. Struts of other lengths may be used as well. For instance, in some examples, longer struts that allow for better wave-isolation of the hull 102 (but at the expense of the stability of the craft 100 and increasing complexity of the retraction system) are utilized.

[0073] In practice, hydrofoils have a limited top speed before cavitation occurs, which results in vapor bubbles forming and imploding on the surface of the hydrofoil. Cavitation not only may cause damage to a hydrofoil but also significantly reduces the amount of lift generated by the hydrofoil and increases drag. Therefore, it is desirable to reduce the onset of cavitation by designing the main hydrofoil 130 and the rear hydrofoil 136 in a way that allows the hydrofoils to operate at higher speeds (e.g., ~20-45 mph) and across the entire required hydrofoil-borne speed envelope before cavitation occurs. For instance, in some examples, the onset of cavitation is controlled based on the geometric design of the main hydrofoil 130 and the rear hydrofoil 136. Additionally, in some examples, the structural design of the main hydrofoil 130 and the rear hydrofoil 136 is configured to allow the surfaces of the hydrofoils to flex and twist at higher speeds, which may reduce loading on the hydrofoils and delay the onset of cavitation.

[0074] Further, in some examples, the distributed blown-wing propulsion system described above further facilitates the delay of onset of cavitation on the main hydrofoil 130 and the rear hydrofoil 136. Cavitation is caused by both (i) the amount of lift generated by a hydrofoil and (ii) the profile of the hydrofoil (which is affected by both the hydrofoil's angle of attack and its vertical thickness) as it moves through water. Reducing the amount of lift generated by the hydrofoil delays the onset of cavitation. Because the blown-wing propulsion system creates additional lift on the main wing 104, the amount of lift exerted on the main hydrofoil 130 and the rear hydrofoil 136 to lift the hull 102 out of the water is reduced. Further, because the main

hydrofoil 130 and the rear hydrofoil 136 do not need to generate as much lift to raise the hull 102 out of the water, their angles of attack may be reduced as well, which further delays the onset of cavitation. In some examples, combining the blown-wing propulsion system with the hydrofoil designs described herein facilitates operating the craft 100 in a hydrofoil-borne mode at speeds above 35 knots before cavitation occurs.

[0075] As noted above, some examples of the main hydrofoil assembly 108 and the rear hydrofoil assembly 110 include one or more main and rear hydrofoil control surfaces 134, 140, respectively. Some examples of the main hydrofoil control surfaces 134 include one or more hinged surfaces on a trailing or leading edge of the main hydrofoil 130 as well as one or more actuators which are operated by the control system of the craft 100 to rotate the hinged surfaces so that they extend above or below the main hydrofoil 130. Some examples of the main hydrofoil control surfaces 134 on the main hydrofoil 130 are operated in a similar manner as the flaps 118 and ailerons 120 on the main wing 104 of the craft 100. In some examples, lowering the control surfaces 134 to extend below the main hydrofoil 130 changes the hydrodynamic shape of the main hydrofoil 130 in a manner that generates additional lift on the main hydrofoil 130, similar to the aerodynamic effect of lowering the flaps 118. In some examples, asymmetrically raising one or more of the control surfaces 134 (e.g., raising a control surface 134 on only one side of the main hydrofoil 130) changes the hydrodynamic shape of the main hydrofoil 130 in a manner that generates a roll force on the main hydrofoil 130, similar to the aerodynamic effect of raising one of the ailerons 120.

[0076] Likewise, some examples of the rear hydrofoil control surfaces 140 include one or more hinged surfaces on a trailing or leading edge of the rear hydrofoil 136 as well as one or more actuators, which are operated by the control system of the craft 100 to rotate the hinged surfaces so that they extend above or below the rear hydrofoil 136. In some examples, the rear hydrofoil control surfaces 140 on the rear hydrofoil 136 are operated in a similar manner as the elevators 126 on the tail 106 of the craft 100. In some examples, lowering the control surfaces 140 to extend below the rear hydrofoil 136 changes the hydrodynamic shape of the rear hydrofoil 136 in a manner that causes the craft 100 to pitch downwards, similar to the aerodynamic effect of lowering the elevators 126. In some examples, raising the control surfaces 140 to extend above the rear hydrofoil 136 changes a hydrodynamic shape of the rear hydrofoil 136 in a

manner that causes the craft 100 to pitch upwards, similar to the aerodynamic effect of raising the elevators 126.

[0077] In some examples, one or both of the main hydrofoil control surfaces 134 or the rear hydrofoil control surfaces 140 include rudder-like control surfaces similar to the rudder 128 on the tail 106 of the craft 100. For instance, some examples of the main hydrofoil control surfaces 134 include one or more hinged surfaces on a trailing edge of the main hydrofoil strut 132 as well as one or more actuators, which are operated by the control system of the craft 100 to rotate the hinged surfaces so that they extend to the left or right of the main hydrofoil strut 132. Similarly, some examples of the rear hydrofoil control surfaces 140 include one or more hinged surfaces on a trailing edge of the rear hydrofoil strut 138 as well as one or more actuators, which are operated by the control system of the craft 100 in order to rotate the hinged surfaces so that they extend to the left or right of the rear hydrofoil strut 138. In some examples, actuating the main hydrofoil control surfaces 134 or the rear hydrofoil control surfaces 140 in this manner changes the hydrodynamic shape of the main hydrofoil strut 132 or the rear hydrofoil strut 138, respectively, which facilitates controlling the yaw of the craft 100 when operating in a waterborne or hydrofoil-borne mode, similar to the effect of actuating the rudder 128 of the craft 100, as described above.

[0078] In some examples, instead of (or in addition to) actuating hinged control surfaces on the main hydrofoil 130 and/or the rear hydrofoil 136, a control system of the craft 100 actuates the entire main hydrofoil 130 and/or the entire rear hydrofoil 136 themselves. In some examples, the craft 100 includes one or more actuators for rotating the main hydrofoil 130 and/or the rear hydrofoil 136 around the yaw axis. In some examples, the craft 100 includes one or more actuators for controlling the angle of attack of the main hydrofoil 130 and/or the rear hydrofoil 136 (i.e., rotating the main hydrofoil 130 and/or the rear hydrofoil 136 around the pitch axis). Some examples of the craft 100 include one or more actuators for rotating the main hydrofoil 130 and/or the rear hydrofoil 136 around the roll axis. Some examples of the craft 100 include one or more actuators for changing a camber or shape of the main hydrofoil 130 and/or the rear hydrofoil 136. Some examples of the craft 100 include one or more actuators for flapping the main hydrofoil 130 and/or the rear hydrofoil 136 to help propel the craft 100 forward or backward. Other examples are possible as well.

[0079] Further, some examples of the craft 100 dynamically control an extent to which the main hydrofoil 130 and/or the rear hydrofoil 136 are deployed based on an operational mode (e.g., hull-borne, hydrofoil-borne, or wing-borne modes) of the craft 100. For instance, in some examples, during hull-borne mode, the rear hydrofoil assembly 110 is partially deployed or retracted to increase turning authority. The amount of partial deployment or retraction may be a function of the desired overall vehicle draft when operating in a shallow water environment. In some examples, during hydrofoil-borne mode, the main hydrofoil assembly 108 is partially retracted to reduce the distance between the hull of the vehicle and the water's surface. This increases the amount of lift generated by the main wing 104 by operating the wing closer to the surface of the water, increasing the effects of the aerodynamic ground effect.

[0080] As noted above, some examples of the main hydrofoil assembly 108 and rear hydrofoil assembly 110 interface with a deployment system that facilitates retracting the respective hydrofoil assemblies 108, 110 into or toward the hull 102 for hull-borne or wing-borne operation and for extending the respective hydrofoil assemblies 108, 110 below the hull 102 for hydrofoil-borne operation. As described further below, in some embodiments, the deployment system is used in connection with extending, retracting, and/or otherwise controlling the positioning of the hydrofoil assemblies 108, 110 during takeoff when the craft is transitioning from hydrofoil-borne operation to wing-borne operation.

E. Hydrofoil Deployment Systems

[0081] Figure 2 illustrates an example of a main hydrofoil deployment system 200 that facilitates retracting and extending of the main hydrofoil assembly 108. As shown, some examples of the main hydrofoil deployment system 200 take the form of a linear actuator that includes one or more brackets 202 that couple the main hydrofoil assembly 108 (by way of the main hydrofoil strut 132) to one or more vertical tracks 204. Some examples of the brackets 202 are configured to move vertically along the tracks 204, such that when the brackets 202 move vertically along the tracks 204, the main hydrofoil assembly 108 likewise moves vertically. Some examples of the brackets 202 are coupled to a leadscrew 206 that, when rotated, causes vertical movement of the brackets 202. Some examples of the leadscrew 206 are rotatable by any of various sources of torque, such as an electric motor coupled to the leadscrew 206 by a gear assembly.

[0082] Some examples of the main hydrofoil deployment system 200 further include one or more sensors 210 configured to detect a vertical position of the main hydrofoil assembly 108. For example, a first sensor senses when the main hydrofoil assembly 108 has reached a fully retracted position and a second sensor senses when the main hydrofoil assembly 108 has reached a fully extended position. However, the main hydrofoil deployment system 200 may include additional sensors for detecting additional discrete positions or continuous positions of the main hydrofoil assembly 108. Some examples of the sensors are included as part of, or otherwise configured to communicate with, the control system of the craft 100 to provide the control system with data that indicates the position of the main hydrofoil assembly 108. Some examples of the control system use this data to determine whether to operate the electric motor to retract or extend the main hydrofoil assembly 108.

[0083] In some examples, such as examples where the linear actuator is not a self-locking linear actuator, the main hydrofoil deployment system 200 includes a locking or braking mechanism for holding the main hydrofoil strut 132 in a fixed position (e.g., in a fully retracted or fully extended position). An example of the locking mechanism corresponded to a dual-action mechanical brake that is coupled to the electric motor, the leadscrew 206, or the gear assembly.

[0084] While the above description provides various details of an example main hydrofoil deployment system 200, it should be understood that the main hydrofoil deployment system 200 illustrated in Figure 2 is for illustrative purposes and is not meant to be limiting. For instance, the main hydrofoil deployment system 200 may include any of various linear actuators now known or later developed that are capable of retracting and extending the main hydrofoil assembly 108.

[0085] Figure 3 illustrates an example of a rear hydrofoil deployment system 300 that facilitates retracting and extending the rear hydrofoil assembly 110. As shown, some examples of the rear hydrofoil deployment system 300 include an actuator 305 to the rear hydrofoil strut 138. When actuated, the actuator 305 causes the rear hydrofoil strut 138 to raise or lower by causing the rear hydrofoil strut 138 to slide vertically along a shaft 307. While not illustrated in Figure 3, in some examples, the rudder 128 is mounted to the shaft 307 such that, when the actuator 305 raises the rear hydrofoil strut 138, the rear hydrofoil strut 138 retracts at least partially into the rudder 128. Additionally, some examples of the rear hydrofoil deployment system 300 include one or more servo motors configured to rotate the rear hydrofoil strut 138 around the shaft. In this respect, in some examples, the rear hydrofoil strut 138 is rotated around

the shaft to act as a hydro-rudder when submerged in water or to act as an aero-rudder when out of the water. Further, because the rudder 128 is mounted to the same shaft 307 as the rear hydrofoil strut 138 and the rear hydrofoil strut 138 can be retracted into the rudder 128, the same servo motor can also be used to control the rotation of the rudder 128.

[0086] The actuator 305 of the rear hydrofoil deployment system 300 may take various forms and may, for instance, include any of various linear actuators now known or later developed that are capable of retracting and extending the rear hydrofoil assembly 110. Further, in some examples, the actuator 305 has a non-unitary actuation ratio such that a given movement of the actuator 305 causes a larger corresponding induced movement of the rear hydrofoil assembly 110. This can help allow for faster retractions of the rear hydrofoil assembly 110, which may be beneficial during takeoff, as described in further detail below.

[0087] Some examples of the main hydrofoil assembly 108 and/or the rear hydrofoil assembly 110 are configured such that, when fully retracted, the hydrofoil assembly is flush, conformal, or tangent to the hull 102. For instance, some examples of the hull 102 include one or more recesses configured to receive the main hydrofoil assembly 108 and/or the rear hydrofoil assembly 110. In this regard, some examples of the main hydrofoil assembly 108 and/or the rear hydrofoil assembly 110 have a shape such that when the main hydrofoil assembly 108 and/or the rear hydrofoil assembly 110 are fully retracted into the recesses of the hull 102, the outer contour of the hull 102 forms a substantially smooth transition at the intersection of the hull 102 and the main hydrofoil assembly 108 and/or the rear hydrofoil assembly 110.

[0088] Other examples of the main hydrofoil assembly 108 and/or the rear hydrofoil protrude slightly below the hull 102 when retracted. These examples of the main hydrofoil assembly 108 and/or the rear hydrofoil assembly 110 are configured to have a non-negligible effect on the aerodynamics of the craft 100. Some examples of the craft 100 are configured to leverage these effects to provide additional control of the craft 100. For instance, in some examples, when the main hydrofoil assembly 108 and/or the rear hydrofoil assembly 110 are retracted but still exposed, the exposed hydrofoil is manipulated in flight to impart forces and moments on the craft 100 similar to an aero-control surface.

[0089] Some examples of the hydrofoil assemblies 108, 110 disclosed herein are mounted on a pivot that is locked underwater but is unlocked to allow the hydrofoil to move around the pivot in the air. At that point, the control surfaces act like trim tabs and are able to effect movement of

the entire unlocked, pivoting hydrofoil, which would otherwise require impractically large and heavy servo motors. This configuration facilitates unlocking and moving of the hydrofoil using a slow servo and/or a combination of control surface movement combined with forward movement through water, and then re-locked such that the hydrofoil is at a selected angle of incidence.

[0090] As noted above, some examples of the main hydrofoil assembly 108 are configured to be retractable. Some examples of the hull 102 include openings through which the strut 132 of the main hydrofoil assembly 108 are retracted and extended. Some examples of the hull 102 are configured to isolate water that enters through these openings (e.g., when the hull 102 contacts the water surface) and to allow for the water to drain from the hull 102 after the hull 102 is lifted out of the water. For instance, some examples of the hull 102 include pockets 142 on each side of the hull 102 aligned above the strut 132. Some examples of the pockets 142 are isolated from the remainder of the interior of the hull 102 so that water that accumulates in the pockets 142 does not reach any undesired areas (e.g., the cockpit, passenger seating area, areas that house the battery system 400, components of the control system of the craft 100, etc.). Further, some examples of the pockets 142 include venting holes or other openings located at or near the bottom of the pockets 142. The venting openings are configured to allow water that enters the pockets 142 to vent out of the pockets 142 when the hull 102 is lifted out of the water.

[0091] Some examples of the main hydrofoil assembly 108 and/or the rear hydrofoil assembly 110 include one or more propellers for additional propulsion when submerged underwater. For instance, in some examples, one or more propellers are mounted to the main hydrofoil 130 and/or the rear hydrofoil 136. In some examples, the propellers are configured to provide additional propulsion force to the craft 100 during hydrofoil-borne or hull-borne operation.

[0092] In some examples, propellers are mounted to the hull 102. The propellers are submerged during hull-borne operation. In some examples, the propellers are configured to provide additional propulsion force to the craft 100 during hull-borne operation.

[0093] Some examples of the main and/or rear hydrofoil assemblies 108, 110 include various failsafe mechanisms in case of malfunction. For instance, in some examples, when one or both of the main and rear hydrofoil deployment systems 200, 300 cannot be retracted due to a malfunction, the craft 100 is configured to jettison the malfunctioning assembly. In this regard, some examples of the main and/or rear hydrofoil assemblies 108, 110 are coupled to the hull 102 by a releasable latch. Some examples of the control system of the craft 100 are configured to

identify a retraction malfunction (e.g., based on data received from the positional sensors 210) and responsively open the latch to release the connection between the hull 102 and the malfunctioning hydrofoil assembly. In some examples, the weight of the malfunctioning hydrofoil assembly is sufficient to jettison the malfunctioning hydrofoil assembly out of the hull 102 when the latch is opened. Some examples of the craft 100 include an actuator or some other mechanism to jettison the malfunctioning hydrofoil assembly out of the hull 102. In some examples, the main and/or rear hydrofoil assemblies 108, 110 are configured to break in a controlled manner upon impact with water. For instance, in some examples, a joint between the main hydrofoil strut 132 and the hull 102 and/or a joint between the rear hydrofoil strut 138 and the hull 102 is configured to disconnect when subjected to a torque significantly larger than standard operational torques at the joints. Other designs for providing controlled breaks are possible as well.

F. Battery System

[0094] Figure 4 illustrates an example of an onboard battery system. In some examples, the battery system 400 is arranged in a protected area 402 of the hull 102 below a passenger seating area 404. Some examples of the battery system 400 are separated from the passenger seating area 404 by a firewall 406 to protect the passengers from harm if a thermal runaway occurs. In this regard, some examples of the craft 100 include a battery management system comprising voltage, current, and/or thermal sensors for detecting thermal runaway or some other fire detection system for detecting a fire in the protected area 402.

[0095] Some examples of the craft 100 include one or more mechanisms for flooding the battery system 400 (e.g., with an inert gas fire, with water, etc.) upon detecting a thermal runaway or a fire in the protected area 402. For instance, some examples of the hull 102 comprise one or more valves or other controllable openings. The control system of the craft 100 is configured to open the valves and/or controllable openings upon detecting a fire in the protected area 402 or thermal runaway in the battery system 400 to allow water to enter the protected area 402 and to extinguish or prevent a fire in the protected area 402.

[0096] In some examples, the battery system 400 is configured to be jettisoned through one or more of the controllable openings in the hull 102 described above. In this regard, in some examples, the weight of the battery system 400 is sufficient to jettison the battery system 400 out

of the hull 102 when the hull 102 is opened. In some examples, the craft 100 comprises an actuator or the like configured to jettison the battery system 400 out of the hull 102.

[0097] In other examples, the craft 100 may take measures to become waterborne in response to detecting a fire in the protected area 402 or thermal runaway in the battery system 400. Some examples of the control system of the craft 100 determine a fire suppression operation to perform based on the operational state of the craft 100 (e.g., operating in hull-borne, hydrofoil-borne, or wing-borne mode). For instance, when operating in hull-borne mode and upon detecting a thermal runaway or a fire in the protected area 402, some examples of the control system are configured to flood the battery system 400 as described above. When operating in hydrofoil-borne or a wing-borne mode, the control system is configured to cause the craft 100 to transition to hull-borne mode upon detecting a thermal runaway or a fire in the protected area 402 and then flood the battery system 400.

G. Control System

[0098] Figure 5 illustrates an example of a control system 500 of the craft 100. As shown, some examples of control system 500 include one or more processors 502, data storage 504, a communication interface 506, a propulsion system 508, actuators 510, a Global Navigation Satellite System (GNSS) 512, an inertial navigation system (INS) 514, a radar system 516, a lidar system 518, an imaging system 520, various sensors 522, a flight instrument system 524, and flight controls 526. In some examples, some or all of these components communicate with one another via one or more communication links 528 (e.g., a system bus, a public, private, or hybrid cloud communication network, etc.)

[0099] Some examples of processors 502 correspond to or comprise general-purpose processors (e.g., a single- or multi-core microprocessor), special-purpose processors (e.g., an application-specific integrated circuit or digital-signal processor), programmable logic devices (e.g., a field-programmable gate array), controllers (e.g., microcontrollers), and/or any other processor components now known or later developed. Further, while the one or more processors 502 are illustrated as a separate stand-alone component of the control system 500, it should also be understood that the one or more processors 502 could comprise processing components that are distributed across one or more of the other components of the control system 500.

[0100] Some examples of the data storage 504 comprise one or more non-transitory computer-readable storage mediums that are collectively configured to store (i) program instructions executable by the one or more processors 502 such that the control system 500 is configured to perform some or all of the functions disclosed herein, and (ii) data that may be received, derived, or otherwise stored, for example, in one or more databases, file systems, or the like, by the control system 500 in connection with the functions disclosed herein. In this respect, the one or more non-transitory computer-readable storage mediums of data storage 504 may take various forms, examples of which may include volatile storage mediums such as random-access memory, registers, cache, etc. and non-volatile storage mediums such as read-only memory, a hard-disk drive, a solid-state drive, flash memory, an optical-storage device, etc. Further, while the data storage 504 is illustrated as a separate stand-alone component of the control system 500, it should also be understood that the data storage 504 may comprise computer-readable storage mediums that are distributed across one or more of the other components of the control system 500.

[0101] Some examples of the communication interface 506 include one or more wireless interfaces and/or one or more wireline interfaces, which allow the control system 500 to communicate via one or more networks. Some example wireless interfaces provide for communication under one or more wireless communication protocols, such as Bluetooth, WiFi (e.g., an IEEE 802.11 protocol), Long-Term Evolution (LTE), WiMAX (e.g., an IEEE 802.16 standard), a radio-frequency ID (RFID) protocol, near-field communication (NFC), and/or other wireless communication protocols. Some example wireline interfaces include an Ethernet interface, a Universal Serial Bus (USB) interface, CAN Bus, RS-485, or similar interface to communicate via a wire, a twisted pair of wires, a coaxial cable, an optical link, a fiber-optic link, or other physical connection to a wireline network.

[0102] Some examples of the propulsion system 508 include one or more electronic speed controllers (ESCs) for controlling the electric motor propeller assemblies 116 distributed across the main wing 104 and, in some examples, across the horizontal stabilizer 124. Some examples of the propulsion system 508 include a separate ESC for each respective propeller assembly 116, such that the control system 500 individually controls the rotational speeds of the electric motor propeller assemblies 116.

[0103] Some examples of the actuators 510 include any of the actuators described herein, including (i) actuators for raising and lowering the flaps 118, ailerons 120, elevators 126, main hydrofoil control surfaces 134, and rear hydrofoil control surfaces 140, (ii) actuators for turning the rudder 128, the main hydrofoil control surfaces 134 positioned on the main hydrofoil strut 132, and the rear hydrofoil control surfaces 140 positioned on the rear hydrofoil strut 138, (iii) actuators for retracting and extending the main hydrofoil assembly 108 and the rear hydrofoil assembly 110, and/or (iv) actuators for performing the various other disclosed actuations of the main hydrofoil assembly 108 and the rear hydrofoil assembly 110. Each of the actuators described herein may include any actuators now known or later developed capable of performing the disclosed actuation. Some examples of the actuators correspond to linear actuators, rotary actuators, hydraulic actuators, pneumatic actuators, electric actuators, electro-hydraulic actuators, and mechanical actuators. Some examples of the actuators correspond to electric motors, stepper motors, and hydraulic cylinders. Other examples are contemplated herein as well.

[0104] Some examples of the GNSS system 512 are configured to provide a measurement of the location, speed, altitude, and heading of the craft 100. The GNSS system 512 includes one or more radio antennas paired with signal processing equipment. Data from the GNSS system 512 may allow the control system 500 to estimate the position and speed of the craft 100 in a global reference frame, which can be used for route planning, operational envelope protection, and vehicle traffic deconfliction by both understanding where the craft 100 is located and comparing the location with known traffic.

[0105] Some examples of the INS 514 include motion sensors, such as angular and/or linear accelerometers, and rotational sensors, such as gyroscopes, to calculate the position, orientation, and speed of the craft 100 using dead reckoning techniques. In some examples, one or more of these components are used by the control system to calculate actuator outputs to stabilize or otherwise control the vehicle during all modes of operation.

[0106] Some examples of the radar system 516 include a transmitter and a receiver. The transmitter may transmit radio waves via a transmitting antenna. The radio waves reflect off an object and return to the receiver. The receiver receives the reflected radio waves via a receiving antenna, which may be the same antenna as the transmitting antenna, and the radar system 516 processes the received radio waves to determine information about the object's location and

speed relative to the craft 100. This radar system 516 may be utilized to detect, for example, the water surface, maritime or wing-borne vehicle traffic, wildlife, or weather.

[0107] Some examples of the lidar system 518 comprise a light source and an optical receiver. The light source emits a laser that reflects off an object and returns to the optical receiver. The lidar system 518 measures the time for the reflected light to return to the receiver to determine the distance between the craft 100 and the object. This lidar system 518 may be utilized by the flight control system to measure the distance from the craft 100 to the surface of the water in various spatial measurements.

[0108] Some examples of the imaging system 520 include one or more still and/or video cameras configured to capture image data from the environment of the craft 100. Some examples of the cameras correspond to or comprise charge-coupled device (CCD) cameras, complementary metal-oxide-semiconductor (CMOS) cameras, short-wave infrared (SWIR) cameras, mid-wave infrared (MWIR) cameras, or long-wave infrared (LWIR) cameras. Some examples of the imaging system 520 are configured to perform obstacle avoidance, localization techniques, water surface tracking for more accurate navigation (e.g., by applying optical flow techniques to images), video feedback, and/or image recognition and processing among other possibilities.

[0109] As noted above, some examples of the control system 500 include various other sensors 522 for use in controlling the craft 100. Examples of such sensors 522 correspond to or comprise thermal sensors or other fire detection sensors for detecting a fire in the hull 102 or for detecting thermal runaway in the battery system 400. As further described above, the sensors 522 may include position sensors for sensing the position of the main hydrofoil assembly 108 and/or the rear hydrofoil assembly 110 (e.g., sensing whether the assemblies are in a retracted or extended position). Examples of position sensors may include photodiode sensors, capacitive displacement sensors, eddy-current sensors, Hall effect sensors, inductive sensors, or any other position sensors now known or later developed.

[0110] Some examples of the sensors 522 facilitate determining the altitude of the craft 100. For instance, some examples of the sensor 522 include an ultrasonic altimeter configured to emit and receive ultrasonic waves. The emitted ultrasonic waves reflect off the water surface below the craft 100 and return to the altimeter. The ultrasonic altimeter measures the time for the reflected ultrasonic wave to return to the altimeter to determine the distance between the craft

100 and the water surface. Some examples of the sensor 522 include a barometer for use as a pressure altimeter. The barometer measures the atmospheric pressure in the environment of the craft 100 and determines the altitude of the craft 100 based on the measured pressure. Some examples of the sensor 522 include a radar altimeter to emit and receive radio waves. The radar altimeter measures the time for the radio wave to reflect off of the surface of the water below the craft 100 to determine a distance between the craft 100 and the water surface. In some examples, these sensors are placed in different locations on the craft 100 to reduce the impact of sensor constraints, such as sensor deadband or sensitivity to splashing water.

[0111] Some examples of the control system 500 are configured to use one or more of the sensors 522 or other components of the control system 500 to help navigate the craft 100 through maritime traffic or to avoid any other type of obstacle. For example, some examples of the control system 500 determine the position, orientation, and speed of the craft 100 based on data from the INS 514 and/or the GNSS 512, and the control system 500 may determine the location of an obstacle, such as a maritime vessel, a dock, or various other obstacles, based on data from the radar system 516, the lidar system 518, and/or the imaging system 520. Some examples of the control system 500 determine the location of an obstacle using the Automatic Identification System (AIS). Some examples of the control system 500 are configured to maneuver the craft 100 to avoid collision with an obstacle based on the determined position, orientation, and speed of the craft 100 and the determined location of the obstacle by actuating various control surfaces of the craft 100 in any of the manners described herein.

[0112] Some examples of the flight instrument system 524 include instruments for providing data about the altitude, speed, heading, orientation (e.g., yaw, pitch, and roll), battery levels, or any other information provided by the various other components of the control system 500.

[0113] Some examples of the flight controls 526 include one or more joysticks, thrust control levers, buttons, switches, dials, levers, or touch screen displays, etc. In operation, a pilot may use the flight controls 526 to operate one or more control surfaces (e.g., flaps, ailerons, elevators, rudder, propulsion propellers, etc.) of the craft 100 to thereby maneuver the craft 100 (e.g., control the direction, speed, altitude, etc., of the craft 100)

[0114] In some examples, the combinations of control surfaces on the craft 100 used by the control system 500 to control operations of the craft 100 depends on the mode of operation of the craft 100 and is determined based at least in part on aspects such as vehicle position, speed,

attitude, acceleration, rotational rates, and/or altitude above water. Table 1 summarizes an example of the relationship between the control surfaces and the operation mode.

Control Surface	Hull-borne	Foil-borne	Wing-borne
Propulsion	Y	Y	Y
Aerodynamic Elevator	N	Y	Y
Aerodynamic Ailerons	N	Y	Y
Aerodynamic Rudder	Y	Y	Y
Aerodynamic Flaps	N	Y	Y
Hydrodynamic Elevator	Y	Y	N
Hydrodynamic Flaps	Y	Y	N
Hydrodynamic Rudder	Y	Y	N

Table 1

[0115] In some examples, the propulsion control surfaces in the table include the propeller assembly 116, as well as any propellers mounted to the hull 102, main hydrofoil assembly 108, or rear hydrofoil assembly 110. In some examples, the aerodynamic elevator control surfaces include elevator 126, the aerodynamic ailerons include ailerons 120, the aerodynamic rudder includes rudder 128 (when not submerged), the aerodynamic flaps include flaps 118, the hydrodynamic elevator includes rear hydrofoil control surfaces 140, the hydrodynamic flaps include main hydrofoil control surfaces 134, and the hydrodynamic rudder includes rudder 128 (when submerged).

[0116] In some examples, when actuating the control surfaces in the various examples, operational modes identified in Table 1 above, the control system 500 executes different levels of stabilization along the various vehicle axes during different modes of operation. Table 2-1 and Table 2-2 below identify alternative examples of stabilization controls that the control system 500 applies during the various modes of operation for each axis of the craft 100. Closed-loop control may comprise feedback and/or feed-forward control.

Vehicle Axis	Hull-borne	Foil-borne	Wing-borne
Pitch Axis	None	Closed-loop control on vehicle ride height	Closed-loop control on vehicle altitude
Roll Axis	None	Closed-loop control around vehicle bank angle = 0	Stabilization and closed-loop control on heading
Yaw Axis	Rate stabilization	Closed-loop control on vehicle heading	Closed-loop control on vehicle heading
Speed Control	Closed-loop control on vehicle GPS Speed	Closed-loop control on vehicle GPS Speed	Closed-loop control on vehicle airspeed

Table 2-1

Vehicle Axis	Hull-borne (E.g., Speed < 7 knots)	Hull-borne (E.g., Speed > 7 knots)	Foil-borne	Wing-borne
Pitch Axis	None	Closed-loop pitch control	Closed-loop control on vehicle ride height	Closed-loop control on vehicle altitude
Roll Axis	None	None	Closed-loop control around vehicle bank angle = 0	Stabilization and closed-loop control on heading
Yaw Axis	Rate stabilization	Rate stabilization	Closed-loop control on vehicle heading	Closed-loop control on vehicle heading
Speed Control	Closed-loop control on vehicle GPS Speed	Closed-loop control on vehicle GPS Speed	Closed-loop control on vehicle GPS Speed	Closed-loop control on vehicle airspeed

Table 2-2

[0117] Further, in some examples, the control system 500 is configured to actuate different control surfaces to control the movement of the craft 100 about its different axes. Table 3 below identifies example axial motions that are affected by the various control surfaces of the craft 100.

Control Surface	Axis Control Function
Propulsion	(a) accelerate and decelerate the vehicle (b) turn the vehicle about yaw axis (c) create a rolling moment
Aerodynamic Elevator	(a) create a pitch up or pitch down moment
Aerodynamic Ailerons	(a) create a rolling moment (b) increase lift on aerodynamic wing (c) create a pitch-down moment
Aerodynamic Rudder	(a) create a yawing moment
Aerodynamic Flaps	(a) increase lift on aerodynamic wing (b) create a pitch-down moment
Hydrodynamic Elevator	(a) create a pitch moment (b) generate heave force on rear hydrofoil
Hydrodynamic Flaps	(a) generate heave force on main hydrofoil
Hydrodynamic Rudder	(a) create a yaw moment

Table 3

III. Example Modes of Operation

A. Hull-Borne Operation

[0118] Figure 6A illustrates an example of the craft 100 when the craft 100 is operating in a hull-borne mode. During this mode, the craft 100 is docked and floating on the hull 102, with the buoyancy of the outriggers 114 providing for roll stabilization of the craft 100. While docked, the battery system 400 of the craft 100 may be charged. In some examples, rapid charging is aided by an open or closed-loop water-based cooling system. In some examples, the surrounding body of water is used in the loop or as a heat sink. In some examples, the craft 100 includes a heat sink integrated into the hull 102 for exchanging heat from the battery system 400 to the

surrounding body of water. In other examples, the heat sink is located offboard in order to reduce the mass of the craft 100.

[0119] Additionally, in some examples, the propeller assemblies 116 are folded in a direction away from the dock while the craft 100 is docked to help avoid collision with nearby structures or people. This folding may be actuated in various ways, such as by metal spring force, hydraulic pressure, electromechanical actuation, or centrifugal force due to propeller rotation. Other examples are possible as well. Further, in some examples, the main hydrofoil assembly 108 and the rear hydrofoil assembly 110 are retracted (or partially retracted) to avoid collisions with nearby underwater structures.

[0120] In some examples, when the craft 100 is ready to depart, the craft 100 uses its propulsion systems, including the propeller assemblies 116 and/or the underwater propulsion system (e.g., one or more outrigger propulsion systems 900, one or more propeller pods mounted to the hull 102, the main hydrofoil assembly 108, and/or the rear hydrofoil assembly 110), to maneuver away from the dock while remaining hull-borne. In some examples, the main hydrofoil assembly 108 and the rear hydrofoil assembly 110 remain retracted (or partially retracted) during this maneuvering to reduce the risk of hitting underwater obstacles near docks or in shallow waterways. However, when there is a limited risk of hitting underwater obstacles, the craft 100 may partially or fully extend the main hydrofoil assembly 108 and/or the rear hydrofoil assembly 110. With the main hydrofoil assembly 108 and/or the rear hydrofoil assembly 110 extended, the craft 100 actuates the main hydrofoil control surfaces 134 and/or the rear hydrofoil control surfaces 140 to improve maneuverability as described above.

[0121] In some examples, at low speeds during hull-borne operation, the control system 500 controls the position and/or rotation of the craft 100 by causing all of the propeller assemblies 116 to spin at the same idle speed, but with a first subset spinning in a forward direction and a second subset spinning in a reverse direction. For instance, in some examples, the control system 500 causes propeller assemblies 116a, 116c, 116e, 116h, 116j, and 116l to idle in reverse and propeller assemblies 116b, 116d, 116f, 116g, 116i, and 116k to idle forward. In this arrangement, the control system 500 causes the craft 100 to make various maneuvers without having to change the direction of rotation of any of the propeller assemblies 116. For instance, to induce a yaw on the craft 100, in some examples, the control system 500 increases the speed of the reverse propeller assemblies on one side of the main wing 104 while increasing the speed of the forward

propeller assemblies on the other side of the main wing 104 and without causing any of the propeller assemblies to transition from forward to reverse or from reverse to forward. For example, idling the propellers at a nominal RPM may allow for a faster response in generating a yaw moment on the craft 100 because the propellers required for generating the yaw moment do not have to increase from zero RPM to the desired RPM value. They can spin from the idle RPM to the desired RPM value.

B. Foil-Borne Maneuvering Operation

[0122] Figure 6B illustrates an example of the craft 100 when the craft 100 is operating in hydrofoil-borne maneuvering mode. During this mode, the craft 100 is configured to, for example, move through harbors and crowded waterways at speeds generally between 20-45 mph. In this regard, the craft 100 may extend the main hydrofoil assembly 108 and the rear hydrofoil assembly 110 (if not already extended) and accelerate using the previously described propulsion system towards a desired takeoff speed. During acceleration, the craft 100 reaches a speed at which the main hydrofoil assembly 108 and the rear hydrofoil assembly 110 alone support the weight of the craft 100, and the hull 102 is lifted above the surface of the water (e.g., by 3-5 ft) so that the hull is clear of any surface waves. After the hull 102 leaves the surface of the water, the drag forces exerted on the craft 100 drop significantly, and the amount of thrust required to maintain acceleration can be reduced. Therefore, in some examples, after the hull 102 has left the water, the control system 500 reduces the speed of the propeller assemblies 116 to lower the thrust of the craft 100.

[0123] Some examples of the control system 500 sustain this operational mode by actively controlling the pitch and speed of the craft 100 so that the main hydrofoil assembly 108 and the rear hydrofoil assembly 110 continue to entirely support the weight of the craft 100. In this regard, some examples of the control system 500 actuate the main hydrofoil control surfaces 134 and/or the rear hydrofoil control surfaces 140 and/or the propulsion system to stabilize the attitude of the craft 100 to maintain the desired height above the surface of the water, vehicle heading, and vehicle forward speed. In this regard, some examples of the control system 500 are configured to detect various changes in the yaw, pitch, or roll of the craft 100 based on data provided by the INS 514 and to make calculated actuations of the main hydrofoil control surfaces 134 and/or the rear hydrofoil control surfaces 140 to counteract the detected changes.

C. Foil-Borne Takeoff Operation

[0124] Figure 7A illustrates an example of the craft 100 when the craft 100 is operating in hydrofoil-borne takeoff mode. During this mode, the craft 100 is configured to, for example, move through open waters and obtain speeds generally between 40-50 mph to facilitate generating the lift required to become wing-borne.

[0125] Referring to Figure 7A, aero lift, LW , generally represents the lift generated by the main wing 104 of the craft 100 but can also include the lift generated by other surfaces such as the tail wing, hull, or propulsive devices such as propellers, rotors, jets, etc. LF generally corresponds to the lift generated by one or more hydrofoils 130, 136 of the craft 100, where LFF corresponds to the lift generated by the front foil and the LFR corresponds to the lift generated by the rear foil. $WCRAFT$ corresponds to the force of gravity exerted on the craft 100 and is also referred to as the weight of the craft. During steady state operation, $WCRAFT$ generally corresponds to $LW+LFR+LFF$ which also corresponds to $LNET$. Throughout the description, the term LF is generally understood to correspond to $LFR+LFF$.

[0126] As previously noted, some experimental craft developed by Applicant that include aero foils were unable to achieve the lift required to sustain flight. In these experimental craft, in an attempt to become airborne, the craft 100 would ramp up to a speed at which point the hydrofoil would breach the surface of the water, as $WCRAFT < Lw + LF$, and $LF > 0$, resulting in $Lw < WCRAFT$. However, in order to takeoff from the water's surface, the aero lift must be greater than or equal to the weight of the craft, however prior to takeoff, the hydrofoils are still under the water's surface, and up until takeoff, have been generating lift ($LF > 0$) as the aerodynamic lift has been insufficient for takeoff up until this point. If the hydro lift and the aero lift sum to greater than the weight of the craft, the vehicle will accelerate upwards and potentially create a premature takeoff condition (prior to condition C0 in Figure 7B) as the aero lift, LW , generated by the wings, etc., of the craft 100 would be insufficient to sustain flight, and, as a result, the craft 100 would come back down and breach the water, ultimately preventing takeoff. The techniques disclosed below ameliorate these problems by controlling the hydrofoil lift vector, LF , specifically by generating downward forces of one or more hydrofoils 130, 136 of the craft 100 to keep the hydrofoils 130, 136 submerged until after the upwards aero lift, LW , is sufficient to allow the craft 100 to sustain flight.

[0127] In some examples, the lift LF is in the downward direction, and is introduced via the hydrofoil(s) as LW increases beyond WCRAFT while the craft 100 is increasing in speed in anticipation of takeoff. This allows the craft 100 to generate a greater overall aero lift, LW, prior to actual takeoff than would otherwise be possible. Then, at the appropriate time (e.g., when LW reaches some predetermined threshold such as the weight of the craft 100 or some margin thereof), the negative lift, LF, can be “released” from the craft 100, and the craft 100 can, as a result, proceed to become wing-borne.

[0128] Figure 7B is an example of a graph 700 that relates these aspects. The relationships shown in the graph 700 and the ways in which various lift forces, thresholds, etc., are depicted are merely examples and are provided to aid understanding of the various operations and procedures described herein. As shown, the net lift, LNET, on the craft 100 initially corresponds to the combination of the aero lift, LW, generated by the wing (e.g., main wing, tail wing, etc.) and the lift, LF, generated by the hydrofoils 130, 136 (e.g., $LNET = LW + LF$). On the left side of the graph 700, the speed of the craft 100 is such that LNET is sufficient to allow the craft 100 to operate in hydrofoil-borne maneuvering mode but is insufficient to allow the craft 100 to become wing-borne. Moving to the right of the graph 700 as speed increases, LW increases with increased craft 100 water speed. To maintain ride height and prevent the hydrofoils 130, 136 from breaching the water surface, LF is reduced in proportion to an increase in LW. For example, LF is adjusted with the speed of the craft 100 to maintain LNET at a margin equal to the weight, WCRAFT, of the craft 100, or small deviations about equal to control ride height. The overall lift provided by the hydrofoils 130, 136 may decrease at the same rate at which lift from the wing is increased towards zero or even become negative with increased speed. For example, just before the speed of the craft 100 reaches the speed associated with condition C0, LF may be reduced to zero. The conditions at C0 (e.g., speed of the craft 100, angle of attack of craft 100, deflection angles of control surfaces, angle of incidence of hydrofoils, etc.) may be such that LF may be zero or close to zero. At C0, the aero lift, LW, generated by the main wing 104 may be expected to be able to transition the craft 100 to a wing-borne mode of operation if the downwards hydrofoil lift, LF, were to be removed as $LW = WCRAFT$. Accordingly, at some time and/or increased speed after this point (e.g., speed associated with condition C1) where $LW > WCRAFT$, LF may be gradually or abruptly removed/released. This, in turn, allows LNET to

approximately equal to or greater than WCRAFT which allows the craft 100 to take off and become wing-borne.

[0129] While not shown in the graph, in some examples, LF is not removed/released as described. Rather, as the craft 100 continues to accelerate, the downwards hydrofoil lift, LF, increases to a maximum downwards amount (e.g., a predetermined maximum amount and/or a maximum amount achievable due to the limitations of the control capabilities of the hydrofoil). As the aero lift, LW, generated by the main wing 105 continues to increase past this maximum amount of downwards hydrofoil lift, LF, LNET increases in the upwards direction beyond WCRAFT and the craft 100 is pulled from the water. This, in turn transitions the craft 100 to a wing-borne mode of operation.

D. Wing-Borne Operation

[0130] Figure 8 illustrates an example of the craft 100 after becoming wing borne. In some examples, once the transition from hydrofoil-borne operation to wing-borne operation is complete, the control system 500 causes the main hydrofoil deployment system 200 and the rear hydrofoil deployment system 300 to respectively retract the main hydrofoil assembly 108 and the rear hydrofoil assembly 110. In some examples, the control system 500 initiates this retraction as soon as the hydrofoil assemblies 108, 110 are clear of the water to reduce the chance of the hydrofoil assemblies 108, 110 reentering the water. The control system 500 may determine that the hydrofoil assemblies 108, 110 are clear of the water in various ways. For instance, in an example, the control system 500 makes such a determination based on a measured altitude of the craft 100 (e.g., based on data provided by the radar system 516, the lidar system 518, and/or the other sensors 522 described above for measuring an altitude of the craft 100). In another example, the sensors 522 may further include one or more conductivity sensors, temperature sensors, pressure sensors, strain gauge sensors, or load cell sensors arranged on the hydrofoil assemblies 108, 110, and the control system 500 may determine that the hydrofoil assemblies 108, 110 are clear of the water-based on data from these sensors.

[0131] Once the craft 100 is clear of the water, the control system 500 continues to accelerate the craft 100 to the desired cruise speed by controlling the speed of the propeller systems 116. In some examples, the control system 500 retracts the flap systems when the craft 100 has achieved sufficient airspeed to generate enough lift to sustain altitude without them and actuates various

control surfaces of the craft 100 and/or applies differential thrust to the propeller systems 116 to perform any desired maneuvers, such as turning, climbing, or descending, and to provide efficient lift distribution. While in wing-borne mode, the craft 100 can fly both low over the water's surface in ground-effect or above ground-effect depending on operational conditions and considerations.

E. Return to Hull-Borne Operation

[0132] To facilitate transitioning from wing-borne to hull-borne mode of operation (See Figure 6A), the control system 500 determines that the hydrofoil assemblies 108, 110 are fully or partially retracted so that the craft 100 may safely land on its hull 102. In some examples, the control system 500 additionally determines and suggests the desired landing direction and/or location-based on observed, estimated, or expected water surface conditions (e.g., based on data from the radar system 516, the lidar system 518, the imaging system 520, or other sensors 522).

[0133] The control system 500 initiates deceleration of the craft 100, for instance, by reducing the speeds of the propeller systems 116 until the craft 100 reaches a desired landing airspeed. During the deceleration, the control system 500 may deploy the flaps 118 to increase lift at low airspeeds and/or to reduce the stall speed. Once the craft 100 reaches the desired landing airspeed (e.g., approximately 50 knots), the control system 500 reduces the descent rate (e.g., to be less than approximately 200 ft/min). As the craft 100 approaches the surface of the water (e.g., once the control system 500 determines that the craft 100 is within 5 feet of the water surface), the control system 500 further slows the descent rate to cushion the landing (e.g., to be less than approximately 50 ft/min). As the hull 102 of the craft 100 impacts the surface of the water, the control system 500 reduces thrust, and the craft 100 rapidly decelerates due to the presence of hydrodynamic drag, the reduction in forward thrust, and the reduction or elimination of blowing air over the wing which significantly reduces lift causing the vehicle to settle into the water. The hull 102 settles into the water as the speed is further reduced until the craft 100 is stationary.

[0134] In some examples, after the craft 100 is settled in the water, the craft 100 is transitioned back to hydrofoil-borne maneuvering mode (See Figure 6B) by extending the hydrofoil assemblies 108, 110 to transition from hull-borne operation to hydrofoil-borne operation in the same manner as described above. In some examples, the control system 500 then sustains the hydrofoil-borne mode at the fifth stage and maneuvers the craft 100 into port while

keeping the hull 102 insulated from surface waves. The control system 500 then reduces the thrust generated by the propeller assemblies 116 to lower the speed of the craft 100 until the hull 102 settles into the water, thereby transitioning that craft back to hull-borne operation at the sixth stage. The control system 500 then retracts the hydrofoil assemblies 108, 110 and performs the hull-borne operations described above to maneuver the craft 100 into a dock for disembarking passengers or goods and recharging the battery system 400.

IV. Example Sensors and Systems

[0135] As noted above in regard to Figure 5, some examples of the craft 100 include various systems and sensors that can be used for a variety of purposes. Examples of such purposes include a) determining the position and orientation of the craft 100, b) determining the type, position and trajectories of above-water and below-water objects that are near the craft 100, and c) monitoring the performance of some systems/components of the craft 100, among other examples.

[0136] In some examples, sensor data from these systems and sensors is communicated to the control system 500 of the craft 100 and the control system 500 fuses or combines the sensor data in such a way as to obtain insight into the environment in which the craft 100 is or will be operating and the state of the craft 100. This insight, in turn, is used by the control system 500 to, for example, control operations (either automatically and/or in combination with operator input) performed by the craft 100 and assess the risk of the craft 100 coming dangerously close to any sensed/detected objects within the environment.

[0137] In some examples, the risk assessment is based in part on factors such as a) the current trajectory of the craft 100, b) the craft's intended path, c) the positions and trajectories of objects detected in the environment, and d) whether the objects are or will be within a threshold distance of points along the craft's trajectory or path. In some examples, the risk assessment is further based on the type/size of the objects. For example, the control system 500 may assess/predict large ships to move slower and less erratically than smaller recreational craft. In some examples, the fused-together sensor data from above-water object detection sensors and the below-water object detection sensors allows the control system 500 to identify surface-piercing objects such as icebergs, buoys, partially submerged containers, logs, etc. The control system 500 may assess/predict these types of objects to be relatively stationary or slow-moving. The control

system 500 may assess/predict other surface-piercing objects, such as swimmers, breaching whales, dolphins, etc., to move somewhat erratically.

[0138] Some examples of the control system 500 convey a conflict risk map graphical representation 1400 (see Figure 14) to the pilot via a pilot-control user interface. The conflict risk map graphical representation may indicate the relative positions and trajectories of objects 1415 near the craft 100, along with an indication of the current trajectory and/or intended path 1405 of the craft 100. The conflict risk map graphical representation 1400 may alert the pilot to those objects that pose the greatest risk of collision. Some examples of the control system 500 also convey via the pilot-control user interface one or more flight paths/plans 1410 that are optimized to mitigate/minimize the risk of collision. In some examples, the pilot may, via the pilot-control user interface, select a particular flight path/plan, and the control system 500 may communicate information to a vehicle control system (VCS) of the craft 100 to cause the craft 100 to travel/operate according to a selected flight path/plan. The VCS, in turn, controls systems of the craft 100 to cause the craft to, for example, change direction, altitude, speed, etc., as needed. In some examples, the control system 500 may automatically (e.g., without pilot input) cause the craft to travel/operate according to a particular flight path/plan.

[0139] In some examples, the sensor data from the systems and sensors described above is communicated to a remote system in communication with the craft 100, such as a remote/cloud server or another system (e.g., a device/system located at a dock), and the remote system uses the information to assess the risk of the craft 100 colliding with or coming dangerously close to any sensed/detected objects. The remote/cloud-based system may base this assessment in part on factors such as the current trajectory of the craft 100, the craft's intended path, and whether the objects are or will be within a threshold distance of points along the craft's trajectory or path. The remote/cloud-based system may then similarly cause the assessment to be conveyed to the pilot via the pilot-control user interface along with one or more flight paths/plans that are optimized to mitigate/minimize the risk of collision. In this regard, in some examples, the remote system communicates this information to the control system 500 of the craft 100 and/or the VCS to cause the craft 100 to travel/operate according to a selected or particular flight path/plan.

[0140] In some examples, the remote system and/or the craft itself receives and aggregates sensor data from other craft or systems operating near the craft 100 and determines, based on the aggregated sensor data, whether one or more objects are in the trajectory or intended path of the

craft 100. For example, the remote system or the craft may receive sensor data from one or more other craft and/or systems that may be near or fixed to an anchoring or taxiing location (e.g., a dock, a matrix of buoys near the dock, etc.) In some examples, as more sensor data is received by the remote system, the remote system may determine particular objects to be permanent features near the anchoring and taxiing locations. Sensor data from these other craft and/or systems may be communicated wirelessly (e.g., via a cellular network, ad hoc network, short-range wireless communication system, etc.) to the remote system and/or the craft 100.

[0141] In some examples, the craft 100 may determine which of its sensors should be used in a particular environment and/or how its sensors should be operated based on sensor data provided by other craft 100. For example, if in a particular area the sensor data provided by one or more other craft indicates that there may be algae in the water or that the water may be choppy, the craft 100 may adjust/configure its sensors to have a sample frequency, dynamic range, sensitivity, etc., that is optimized to sense the particular conditions sensed by the other craft. In some examples, the craft 100 may activate particular sensors that are not otherwise activated when such particular conditions are detected by other craft. For example, the craft 100 may activate thermal sensors that may not be used under other circumstances when seaweed is known to be present. In some examples, after sensing particular conditions (e.g., while landing or approaching a landing area), a particular craft may broadcast an indication of the sensed particular conditions to other craft that may be preparing to land in the same area and those other craft may, in turn, adjust their sensor operations to optimize one or more sensors to sense the particular conditions. In some examples, the type of information specified in the indication broadcast by the particular craft may depend on the nature of the particular condition. For example, if seaweed is detected, the indication may include one or more images of the seaweed that are captured by one or more cameras of the craft 100 along with location information that specifies the location of the seaweed. If the water is choppy, the indication may only specify the location of the choppy water.

[0142] In some examples, one or more sensors may sweep between positions to scan a larger FOV of the environment. For example, the sensors may sweep 180 degrees, 360 degrees, etc. In some examples, the sensors may continually sweep between positions and at a particular frequency. In some examples, the sweep angle and/or the sweep frequency is dynamically controlled based on various considerations, such as the speed, altitude, operating mode, etc., of

the craft. For example, one or more forward facing sensors might sweep 180-360 degrees when the craft 100 is moving relatively slowly (e.g., while the craft is hull borne). The sweep angle may be decreased to 45 degrees or less when the craft 100 is moving relatively fast (e.g., while the craft 100 is hydrofoil borne, wing borne, etc.) The sweep angle and/or the sweep frequency may be dynamically controlled based on other considerations as well such the sensed environmental conditions, whether there are obstructions sensed near the craft 100, etc.

A. Position, Speed, Orientation and Terrain Sensing

[0143] Some examples of systems and sensors from which the control system 500 fuses sensor data correspond to position, speed, and orientation systems/sensors. The sensor data from these systems/sensors facilitate causing the craft 100 to perform operations such as causing the craft 100 to travel along a particular path or trajectory (e.g., by adjusting the heading, speed, height/altitude, etc., of the craft 100). For instance, as noted above in regard to Figure 5, some examples of the control system 500 receive sensor data from a flight instrument system 524, an inertial navigation system (INS) 514, and/or one or more altitude/height sensors of the craft 100.

[0144] Some examples of the flight instrument system 524 include/receive sensor data from a 3-axis sensor (e.g., a fiber optic gyroscope (FOG)) that senses the roll, pitch, and yaw of the craft 100. Some examples of the INS 514 receive global navigation satellite system (GNSS) signals that provide centimeter-level accurate global positioning coordinates of the craft 100 together with the heading, roll and pitch of the craft 100. In some examples, the control system 500 uses information provided by these systems to determine the orientation of the craft 100 along with the trajectory of the craft 100.

[0145] Figures 9A and 9B illustrate examples of height sensors 905 that facilitate sensing the height of the craft 100. Examples of the height sensors 905 facilitate determining the ride height of the craft 100 while on the water and/or the altitude of the craft 100 while airborne. Some examples of the height sensors 905 include radar altimeters 905a, 905b and ultrasonic sensors 905c, 905d, 905e, 905f. In some examples, the height sensors 905 are positioned on surfaces of the craft 100 that have an unobstructed or mostly unobstructed view of the water surface (e.g., unobstructed by the main hydrofoil 130 and/or the rear hydrofoil 136), such as the lower surface of the underside of the wings, the underside of the box tail, etc. In some examples, height sensors 905 may also be positioned on other sections of the craft 100, such as under hull 102, under the

main hydrofoil 130 and/or rear hydrofoil 136, under the outriggers 114 at the wing tips, etc. Height sensors 905 at these other sections can be used when these sections are above the water surface such as when the craft is traveling in-ground effect.

[0146] The radar altimeters 905a, 905b generally provide more frequent distance measurements than the ultrasonic sensors 905c, 905d, 905e, 905f, are capable of sensing distances of several hundred feet, and have a relatively wide field of view (“FOV”) 910a, 910b. Some examples of the ultrasonic sensors 905c, 905d, 905e, 905f, on the other hand, provide more precise but less frequent distance measurements, can only accurately measure distance to about 20-30 feet, and have a relatively narrow FOV 910c, 910d. As such, the radar altimeters 905a, 905b are more particularly suited to measuring the altitude/distance of the craft 100 from the water surface when the craft 100 is in flight, for example, traveling in-ground effect (e.g., at altitudes of 30 feet or more), and the ultrasonic sensor 905c, 905d, 905e, 905f are more suited to measuring the distance between the craft 100 when the craft 100 is not in-ground effect such as when the main hydrofoil 130 and rear hydrofoil 136 are about to enter the water and/or after the craft 100 is hydrofoil borne.

[0147] In some examples, the control system 500 may determine the altitude sensors 905, or a particular combination of altitude sensors 905, to use based on the operating mode of the craft 100. For example, the radar altimeters 905a, 905b may be used to determine the altitude of the craft 100 when the craft 100 is traveling in-ground effect (e.g., when the craft is airborne), and the ultrasonic sensors 905c, 905d, 905e, 905f may be used to determine the altitude of the craft 100 when the craft 100 is not traveling in-ground effect such as when the hydrofoils of craft 100 are about to enter the water, while the craft is hydrofoil borne, etc.

[0148] In some examples, the control system 500 may determine the altitude of the craft 100 as a weighted combination (such as a weighted average) of the readings from the two types of sensors. Sensor data from the radar altimeters 905a, 905b may be more heavily weighted than sensor data from the ultrasonic sensors 905c, 905d, 905e, 905f when the craft 100 is traveling in-ground effect, whereas sensor data from the ultrasonic sensors 905c, 905d, 905e, 905f may be more heavily weighted than sensor data from the radar altimeters 905a, 905b when the craft 100 is not traveling in-ground effect such as when the hydrofoils of craft 100 are about to enter the water, while the craft 100 is hydrofoil borne, etc.

[0149] In some examples, sensor data from a given sensor may be “disregarded” when it begins to provide a value that is outside of a given range. For example, particular ultrasonic sensors 905c, 905d, 905e, 905f may be known to be accurate at measuring distances up to a particular predetermined height, above which the sensor data may be disregarded. One example of such a particular predetermined height may be approximately 25 feet. In this case, when the sensor data indicates a distance/height beyond 25 feet, the sensor data may be disregarded.

[0150] As indicated above, some examples of the height sensors 905 may be positioned such that they have a partially obstructed view of the water surface. In some cases, the obstruction may be caused by a component of the craft 100 having a known position and configuration, such as the craft hydrofoil(s) including when such hydrofoil(s) are extended. As such, in some examples, sensor data from such sensors may be filtered to remove artifacts associated with the component causing the obstruction to improve the reliability and/or usefulness of the sensor data.

[0151] In some examples, one or more of the radar altimeters 905a, 905b used for height tracking and perhaps additional or different radar sensors or other types of sensors arranged on the craft 100 to scan/sense the area below the craft 100 can be operated to facilitate terrain mapping. For instance, one or more radar sensors can be operated alone or in combination to provide synthetic aperture radar sensing capabilities. For example, a sequence of acquisitions from the radar sensors can be combined while the craft 100 is moving to simulate a much larger radar antenna capable of providing a relatively high-resolution view of the terrain. In some examples, the terrain data captured by several similarly equipped craft 100 can be combined to map the terrain of a large area such as the terrain near a dock or of a landmass over which the craft 100 may fly. In this regard, in some examples, the craft 100 may communicate captured terrain data to a remote system that is configured to combine terrain data received from other craft and perhaps other sources to map the terrain of a particular area. The craft 100 may receive the combined terrain data from the remote system as needed. For example, the craft 100 may obtain the combined terrain data associated with a target area as the craft 100 approaches the target area. In some examples, the craft 100 may alter its heading, altitude, speed, etc., based on the terrain of the target area. For example, the craft 100 may dynamically adjust its altitude to maintain a relatively constant height over the target area, the craft 100 may adjust its heading to steer clear of particular features of the target area (e.g., hills, trees, etc.), etc.

B. Above-Water-Object Sensing

[0152] Some examples of systems and sensors from which the control system 500 fuses sensor data correspond to systems/sensors that facilitate the detection of above-water objects. For instance, some examples of the control system 500 receive sensor data from, for example, an automatic identification system (AIS) of the craft 100 and object detection sensors placed on various positions of the craft 100.

[0153] Some examples of the AIS receive signals transmitted by remote AIS systems associated with particular objects near the craft 100 (e.g., other craft, buoys, etc.). The AIS systems of the other objects transmit radio frequency (RF) signals that facilitate identifying the objects (e.g., a particular object type, call sign, etc.). In some examples, the RF signals communicated by the AIS systems of the other objects facilitate determining the position, speed, heading, and/or trajectory of these objects.

[0154] Figure 10 illustrates examples of above-water-object sensors 1005, 1010, 1015 placed on various positions of the craft 100. The above-water-object sensors 1005, 1010, 1015 include forward-looking sensors 1005, rearward-looking sensors 1010, and side-looking sensors 1015. Some additional examples of above-water-object sensors 1005 include sensors oriented to look in different directions and perhaps oriented to look back toward the craft 100. In this regard, in some examples, sensor data generated by sensors oriented to look back toward the craft 100 may be processed/filtered (e.g., by the pre-processing logic 1310 of Figure 13) to remove artifacts in the sensor data associated with interference due to components of the craft 100.

[0155] Some examples of these object detection sensors 1005, 1010, 1015 correspond to electro-optical (EO) color cameras, infrared (IR) cameras, and radar systems (e.g., phased array). Other examples of above-water-object sensors 1005, 1010, 1015 correspond to or involve the use of AIS transponders, light detection and ranging (LIDAR) systems, ultrasonic transducers, passive RF systems, acoustic systems, etc. Some other examples of the object detection sensors include gravitational sensors and electromagnetic sensors. The gravitational sensors are capable/configured to detect minute localized changes in the force of Earth's gravity caused by variations in the density of the water below the craft 100 (e.g., due to the presence of objects in the water). The electromagnetic sensors are configured to sense the strength and direction of an electromagnetic field and may operate in a manner similar to the ampullae of Lorenzini of some sea creatures.

[0156] Some examples of these object detection sensors 1005, 1010, 1015 are capable of sensing objects within a particular field of view (FOV), for example, a 90° FOV. In this regard, in some examples, multiple object detection sensors 1005, 1010, 1015 are arranged on the craft 100 in such a way as to facilitate “stitching” together the FOVs provided by the object detection 1005, 1010, 1015 to provide a relatively large FOV, including up to a 360° FOV.

[0157] For example, a first sensor 1010 positioned towards the rear of the craft 100 may have a 90° FOV of the scene behind the craft 100. Similarly, a second sensor 1005a positioned at the nose of the craft 100 may have a 90° FOV of the scene in front of the craft 100. Second and third sensors 1015a, 1015b positioned on respective port and starboard sides of the craft 100 may have 90° FOVs of the scenes that are to the left and to the right of the craft 100, respectively.

[0158] In general, the object detection sensors 1005, 1010, 1015 are placed in such a manner so that elements/components of the craft 100 do not obstruct the FOV of the object detection sensors 1005, 1010, 1015, or such that obstruction is mitigated or limited. For instance, some object detection sensors 1005, 1010, 1015 may be placed on higher surfaces of the craft 100 so that they may achieve the furthest possible line of sight without obstruction.

[0159] In some examples, the craft 100 includes multiple forward-looking sensors to provide a degree of redundancy and to provide an increased forward-looking FOV. For example, some examples of forward-looking sensors 1005a are positioned on or near the nose of the craft 100 and/or near the canopy of the craft 100 (e.g., forward-looking sensor 1005b). The forward-looking sensor 1005a placed on the nose of the craft 100 might advantageously provide a field of view of objects that are close to the craft 100. However, this sensor 1005a might also be prone to splashing/obstruction and not be able to see very far. On the other hand, a sensor 1005b placed in the canopy of the craft 100 might be capable of seeing far and might not be susceptible to splashing. However, such a sensor 1005b might be more susceptible (than when positioned elsewhere) to obstruction by the craft 100, such as by the nose of the craft 100 and/or the wing of the craft 100. This might prevent the canopy sensor from being reliable, at least to a desired amount of reliability, with respect to sensing objects that are relatively close.

[0160] In some examples, forward-looking sensors 1005c may be positioned on, in, or near the box tail of the craft 100.

[0161] In some examples, forward-looking sensors 1005d, 1005e are positioned along leading edges of the main wing 104 of the craft 100. In some examples, the forward-looking sensors

1005d, 1005e may be placed on sections of the main wing 104 that are expected to receive little to no spray (e.g., away from the outriggers 114, near the hull 102) during normal operation. The forward-looking sensors 1005d, 1005e may be spaced away from the propeller assemblies 116 when propeller spray is an issue and/or the propellers themselves obstruct the FOV of the forward-looking sensors 1005d, 1005e. In this regard, in some examples, the forward-looking sensors 1005d, 1005e may nevertheless be placed behind the propeller assemblies 116 and sensor data generated by these forward-looking sensors 1005d, 1005e may be processed/filtered (e.g., by the pre-processing logic 1310 of Figure 13) to remove artifacts in the sensor data associated with interference due to rotation of the propeller assemblies 116.

[0162] Some examples of rearward-looking sensors 1010a may be positioned on the rear side/end of the box tail. Some examples of side-looking sensors 1015a, 1015b may be positioned at the wing tips, as shown, and/or on the sides of the box tail. In some examples, rearward-looking sensors 1010 and/or side-looking sensors 1015a, 1015b may be placed on other sections of the craft 100 that respectively provide unobstructed views behind and to the side of the craft 100.

[0163] In some examples, rearward-looking sensors 1010b, 1010c are positioned on the inner most propeller pods and forward-looking sensors 1005f, 1005g are positioned near the box tail wing tips. In some examples, these sensors are used, among other reasons, to facilitate maneuvering the craft 100 to a dock.

[0164] In some examples, different combinations of sensors are used during different modes of operations of the craft 100. For example, at higher speeds (e.g., when the craft 100 is airborne), information provided by the side and/or rear-facing sensors may not be particularly useful. As such, when the craft 100 is traveling at higher speeds, these sensors may be disabled, or sensor data provided by these sensors disregarded and the forward-looking sensors may be used exclusively for object detection. At lower speeds (e.g., when the craft is landing, hydrofoil borne, hull-borne, etc.), additional sensors for sensing objects to the sides of the craft 100 and to the rear of the craft 100 may also be used.

[0165] In some examples, the detection range of the sensors depends on the operating mode. For example, when the craft 100 is hull-borne and moving relatively slowly (e.g., less than 20 knots), the particular sensors and/or combination of sensors used, and/or the detection range of the sensors, may be reduced to concentrate on sensing objects that are within, for example, 200

yards of the craft 100. On the other hand, when the craft 100 is moving relatively quickly (e.g., greater than 20 knots), the particular sensors and/or combination of sensors used, and/or the detection range of the sensors, may be increased. In an example, alternative and/or additional sensors may be used to increase the detection range.

[0166] In some examples, such as when the craft 100 is hydrofoil-borne and moving somewhat fast, the sensors may be configured to concentrate on sensing objects that are up to 500 yards away. When the craft is airborne and, therefore, moving faster, the sensors may be configured to concentrate on sensing objects that are up to 1000 to 2000 yards away. In this regard, in some examples, when the craft 100 is airborne, the field of view may be narrowed (e.g., by using the forward-looking sensor 1005d on the nose of the craft 100) so that the sensors are primarily concentrating on objects that are in front of the craft 100.

[0167] In some examples, the craft 100 includes a periscope sensor 1020 that includes a telescopically deployable arm and a sensor. The sensor is coupled to the first end of the arm, and the second end of the arm is coupled to the craft 100. Placing the sensor at the first end of the arm meaningfully increases the height of the sensor above the craft 100, which in turn increases the sensing range of the sensor. The length of the arm may be any suitable length. In an example, the arm may be as short as a few inches, or may be up to 5 meters long. In an example, the arm is dynamically and/or adjustably deployable to a length that is desired in a given instance. In an example, the length of the arm may be, or may be deployed, to a length of 5 feet. In another example, the length of the arm may be, or may be deployed, to a length of 3 meters. In another example, the arm may be dynamically adjustable in its orientation horizontally such that the sensor can be rotated to facilitate tracking an object and/or scanning an area to the front, behind or sides of the craft 100 without having to rotate the craft 100. Alternatively, if the craft 100 is free floating and perhaps rotating due to wind, the sensor can be rotated in the opposite direction to maintain its relative orientation with respect to one or more other objects being scanned.

[0168] In some examples, the periscope sensor 1020 is positioned on the top of the hull 102, opposite the hydrofoils. Some examples of periscope sensor 1020 use radar sensing to detect objects. In some examples, when deployed, the periscope sensor 1020 facilitates seeing objects up to 4-5 km out. In some examples, the periscope sensor 1020 is only deployed when the craft

100 is traveling below a threshold speed (e.g., below 30 knots), and/or when the craft is not moving at all.

[0169] In some examples, the periscope sensor 1020 is deployed as part of a pre-takeoff procedure and/or as part of a takeoff procedure. In an example, the periscope sensor 1020 is deployed after a takeoff indication is received. In this case, the craft 100 may help determine whether a takeoff can be safely performed based on whether any objects that may pose a risk are detected by the periscope sensor 1020. If no such objects are detected, then the craft 100 may be allowed to take off. On the other hand, if objects are detected, takeoff may be aborted, or operations may be performed by the craft 100 so that the craft 100 will avoid hitting the object. For example, the craft 100 may rotate to an extent or change its heading to an extent until there are no longer any objects in its path. After determining that there are no objects posing a risk to take off, the craft 100 may proceed to take off.

C. Below-Water-Object Sensing

[0170] Figure 11 illustrates examples of below-water-object sensors 1105 placed on various positions of the craft 100. Some examples of the below-water-object sensors 1105 may be used while underwater (e.g., when the craft 100 is hull borne) or when above the water (e.g., when the craft is taking off/landing, foiling, flying, etc.). Some examples of the below-water-object sensors 1105 correspond to sonar sensors and electro-optical (EO) cameras. Some other examples of the below-water-object sensors 1105 include gravitational sensors and electromagnetic sensors. The gravitational sensors are capable/configured to detect minute localized changes in the force of Earth's gravity caused by variations in the density of the water below the craft 100 (e.g., due to the presence of objects in the water). The electromagnetic sensors are configured to sense the strength and direction of an electromagnetic field and may operate in a manner similar to the ampullae of Lorenzini of some sea creatures.

[0171] Some examples of the below-water-object sensors 1105 are configured as forward-looking sensors 1105a, 1105b and or somewhat downward-looking sensors 1105c, 1105d. Some examples of these sensors have a 90° FOV of the below-water scene that is in front of the craft 100 to facilitate the detection and monitoring of objects that are below the surface of the water and in front of the craft 100. Some examples of the craft 100 may include additional below-water-object sensors 1105 that are configured/positioned to provide FOVs of below-water scenes

that are to the sides and/or rear of the craft 100 to facilitate the detection and monitoring of objects that are below the surface of the water and to the side and/or rear of the craft 100. In some examples, sensor data from these below-water-object sensors 1105 may be stitched together to provide a widened range of view, up to a 360° view, of the underwater landscape below the craft 100.

[0172] In some examples, forward-looking sensors 1105a, 1105b may be positioned on the leading edge of the main hydrofoil 130 and/or the rear hydrofoil 136 (e.g., in the middle of the leading edge of the respective hydrofoils, near the tips/ends of the respective hydrofoils, etc.) and/or along the main hydrofoil strut 132 and/or the rear hydrofoil strut 138 (e.g., one or more sensors arranged along the leading-edge length of the respective hydrofoil struts). In some examples, multiple below-water-object sensors 1105 1105 may be positioned on the respective hydrofoils and/or struts such that sensor data from these below-water-object sensors 1105 may be stitched together to provide a 360° view of the underwater landscape below the craft 100.

[0173] In some examples, downward-looking sensors 1105c, 1105d may be positioned on the underside of the hull 102 near the nose of the craft 100, on the leading surface of the outriggers 114, etc. These sections of the craft may, for example, facilitate underwater object detection when the craft 100 is hull-borne.

D. Craft-Performance Sensing

[0174] Some examples of systems and sensors from which the control system 500 fuses sensor data correspond to systems/sensors that facilitate monitoring the performance of systems/components of the craft 100. For instance, some examples of the control system 500 receive sensor data from actuator position sensors, rotation rate (RPM) sensors, and other sensors placed on various positions of the craft 100. Some examples of the actuator position sensors are coupled to actuators used for adjusting control surfaces such as the flaps 118, ailerons 120, elevators 126, rudders 128a, 128b, 128n, vertical stabilizer 122, control surfaces of the main hydrofoil 130 and the rear hydrofoil 136, etc. Sensor data communicated by these actuator position sensors allows the control system 500 to determine or observe the respective deflection angles of these control surfaces.

[0175] Some examples of the actuator position sensors are coupled to actuators used for extending and retracting the main hydrofoil 130 and the rear hydrofoil 136. Sensor data

communicated by these actuator position sensors allows the control system 500 to determine or observe the amount by which the main hydrofoil 130 and the rear hydrofoil 136 are extended.

[0176] Some examples of the RPM sensors are coupled to the propeller assemblies 116, such as the respective shafts of the propeller assemblies. Sensor data communicated by the RPM sensors allows the control system 500 to determine or observe the respective rotation rates of the propeller assemblies 116. In some examples, sensor data communicated by the various sensors is provided as input to one or more closed-loop algorithms implemented by the control systems 500 as negative feedback for causing the various control surface deflection angles, hydrofoil extension amounts, propeller assembly 116 rotation rates, etc., to be adjusted to various target settings.

[0177] In some examples, one or more of the sensors described above that facilitate above-water-object sensing and below-water-object sensing can also be used to facilitate craft-performance sensing. For example, as noted above, some examples of above-water-object sensors 1005 may be oriented to look back toward the craft 100. The sensor data generated by these sensors may specify remote objects (e.g., ships or other craft) and also components of the craft (e.g., the main wing 104, box tail, hydrofoils, etc.). In some examples, the sensor data associated with these components facilitates determining/monitoring the state/configuration of these components such as the respective deflection angles of various controls surfaces of the main wing 104, box tail, the main hydrofoil 130 and/or the rear hydrofoil 136. In some examples, the respective extension amounts of the main hydrofoil 130 and/or the rear hydrofoil 136 may be determined/monitored. The state/configuration of other components of the craft 100 may be similarly determined/monitored using such dual-purpose sensors.

[0178] In some examples, these “craft performance sensors” may be used as redundant or secondary “out of loop” sensors to provide independent/separate information regarding various operating states of components of the craft 100. For example, the craft 100 may have one or more first sensors for determining the respective locations/positions of the main hydrofoil 130 and the rear hydrofoil 136 and that are used for actual control of the position/deployment of the main hydrofoil 130 and the rear hydrofoil 136. One or more separate/redundant sensors may be provided to independently observe the state (perhaps using a different sensing mechanism than the first sensors) to validate the operation of the main hydrofoil 130 and the rear hydrofoil 136 and to confirm that the first sensors are reading correctly.

[0179] Figure 12 illustrates examples of other sensors 1205 that facilitate monitoring operations performed by the craft 100. Some examples of the other sensors 1205a, 1205b may be positioned on the underside of the hull 102 and may correspond to sonar-based sensors, electro-optical (EO) cameras, laser-based sensors, etc., that facilitate monitoring the state/configuration of the main hydrofoil 130 and the rear hydrofoil 136. For example, the control system 500 may determine via sensor data communicated from these sensors 1205a, 1205b whether there is any debris on the main hydrofoil 130 and the rear hydrofoil 136. The control system 500 may determine via sensor data communicated from these sensors 1205a, 1205b the respective deflection angles of one or more control surfaces on the main hydrofoil 130 and the rear hydrofoil 136, the respective extension amounts of the main hydrofoil 130 and the rear hydrofoil 136, etc. In this regard, the control system 500 may use the sensor data provided by these sensors 1205a, 1205b in conjunction with the sensor data provided by the corresponding hydrofoil actuator position sensors described above to determine/control the configuration of the main hydrofoil 130 and the rear hydrofoil 136.

[0180] Some examples of the sensors 1205a, 1205b may facilitate determining whether the main hydrofoil 130 and/or the rear hydrofoil 136 are cavitating. For example, a laser-based sensor may emit laser light to the regions behind the main hydrofoil 130 and the rear hydrofoil 136. Bubbles generated behind the main hydrofoil 130 and/or the rear hydrofoil 136 may cause the laser light to be reflected to and sensed by the laser-based sensor. In some examples, the control system 500 may cause the speed of the craft 100 to be reduced (e.g., by reducing thrust) to eliminate or reduce cavitation.

[0181] Some examples of the sensors 1205c, 1205d may be positioned on the respective lower ends of the main strut 132 and the rear strut. Some examples of these sensors 1205c, 1205d may correspond to pressure sensors that facilitate measuring the pressure of the water at the respective lower ends of the main strut 132 and the rear strut. This, in turn, facilitates determining the depth of the main hydrofoil 130 and the rear hydrofoil 136. In some examples, the control system 500 adjusts the extension amount of the main hydrofoil 130 and the rear hydrofoil 136 based on sensor data provided by these sensors 1205c, 1205d to have a target depth below the water surface.

V. Conflict Detection and Resolution Control (CDRC) Logic

[0182] As noted above, some examples of the control system 500 fuse together the sensor data provided by the various sensors described above to obtain insight into the environment in which the craft 100 is or will be operating and the state of the craft 100. This insight, in turn, is used by the control system 600 to, for example, control operations performed by the craft 100 and assess the risk of the craft 100 coming dangerously close to any sensed/detected objects within the environment.

[0183] Figure 13 illustrates example conflict detection and resolution control (CDRC) logic 1300 implemented by some examples of the control system 500 for generating these and other insights. In some examples, the logic 1300 illustrated in the figure is implemented via instruction code that is executed by one or more processors of the control system 500 of the craft 100 that causes the control system 500 to control, alone or in cooperation with other subsystems of the craft 100, components of the craft 100 to perform operations associated with the logic.

Additionally, or alternatively, one or more of the operations can be implemented or controlled by dedicated hardware, such as via one or more application-specific integrated circuits (ASICs).

Some aspects of the operations may be executed as a result of or in combination with inputs received from an operator of the craft 100 or other subsystems of the craft 100. Other aspects of the operations may alternatively and/or additionally be executed automatically.

[0184] In some examples, one or more aspects of the CDRC logic 1300 may, alternatively or additionally, be implemented by a remote system in communication with the craft 100. For example, the sensor data shown in the figure may be communicated to CDRC logic 1300 implemented by the remote system, and the remote system may communicate to the craft 100 data/information that may, in turn, be communicated to the vehicle control system (VCS) 1335 and/or the pilot user interface 1340 shown in the figure.

[0185] Referring to Figure 13, sensor data from sensors 1305 such as those described above, is input to pre-processing sub-logic 1310, which pre-processes the sensor data and communicates the processed sensor data to object detection/classification sub-logic 1315 and sea state characterization and postprocessing sub-logic 1320. Some examples of the pre-processing sub-logic 1310 perform calibration operations to, for example, a) normalize values specified in the sensor data, b) synchronize sensor data received from the various sensors 1305 (e.g., using

timestamp information specified in the sensor data), and/or c) filter the sensor data to remove values that may be outliers (e.g., values that are outside of an expected range).

[0186] Some examples of the sea state characterization and postprocessing sub-logic 1320 implement operations for characterizing the conditions of the water surface, such as the water current speed and direction, average and peak wave heights, wave frequencies, etc. These and other examples for characterizing the sea state and that are implemented by some examples of the sea state characterization and postprocessing sub-logic 1320 are described in U.S. App. 17/875,942, entitled “Determining Characteristics of a Water Surface Beneath a Vehicle in Motion,” filed July 28, 2022, which is incorporated herein by reference in its entirety. In some examples, information that characterizes the sea state is communicated to the VCS 1335 of the craft 100 directly after the processing performed by sea state characterization and postprocessing sub-logic 1320. The operation of the VCS 1335 is described in more detail below.

[0187] Some examples of the object detection/classification sub-logic 1315 include machine learning (ML) logic that is trained to identify objects specified in the sensor data and to classify the objects. Object data indicative of the classified objects (e.g., object type, object size, etc.) is communicated to multi-target tracker sub-logic 1325. Some examples of the ML logic include hardware, software, or a combination thereof that is specifically configured to implement or assist in the implementation of various supervised and unsupervised machine learning models. Within examples, these can involve the implementation of a Holt-Winters algorithm, an exponential time smoothing (ETS) algorithm, an artificial neural network (ANN), a recurrent neural network (RNN), convolutional neural network (CNN), a seasonal autoregressive moving average (SARIMA) algorithm, a network of long short-term memories (LSTM), a gated recurring unit (GRU) algorithm. Examples of the ML logic can implement other machine learning (ML) logic and/or AI algorithms. In some examples, the ML logic is trained using sensor data associated with the various sensors, and that is known to specify different categories of objects.

[0188] In some examples, ML logic similar to that described above is implemented by a remote system (e.g., a cloud-based server). The sensor data received by the object detection/classification sub-logic 1315 may then, alternatively or additionally, be communicated to the remote system, and the remote system may communicate an indication to the craft 100 of any objects specified in the sensor data that were inferred by the ML logic of the remote system.

[0189] Some examples of the multi-target tracker sub-logic 1325 perform various operations to track the respective paths of objects of interest. These operations involve determining whether one or more objects specified in the object data received from the object detection/classification sub-logic 1315 are moving along a path or track and, if so, associating those objects with the determined path or track. Afterward, objects associated with tracks of interest are selected for further consideration. Selected objects correspond to those predicted to have a track or path that may interfere with the trajectory or intended path of the craft 100. The locations of the selected objects are compared against the locations of known objects to assess whether the detected objects correspond to fixed objects (e.g., a lighthouse, cliff, dock, etc.) as opposed to moving objects. Objects assessed to be fixed may be removed from further consideration. The tracks of the remaining objects are compared to identify duplicate objects. Object data associated with duplicate objects may be removed, or the object data associated with corresponding duplicate objects may be merged. Statistical techniques (e.g., covariance) may then be used to determine a confidence score associated with each remaining object and its associated path or track. Object data associated with objects having a confidence score that exceeds a threshold confidence amount is then input to conflict detection and resolution sub-logic 1330.

[0190] Some examples of the conflict detection and resolution sub-logic 1330 perform operations that involve estimating a conflict (e.g., the craft colliding or coming within a threshold distance of an object) based on the combination of tracks specified in the object data and the craft's current trajectory or its intended path. Conflict estimates are then used to generate a conflict risk map that specifies potential collision zones. In some examples, after determining the conflict risk map, a conflict avoidance path 1410 is determined for avoiding the potential conflict zones.

[0191] As shown in Figure 14, in some examples, a conflict risk map graphical representation 1400 that indicates the current path 1405 of the craft 100 and the conflict avoidance path 1410 that the craft 100 should take to avoid a conflict is generated and communicated to the pilot user interface 1340. Some examples of the conflict risk map graphical representation 1400 indicate one or more objects 1415 detected by one or more sensors of the craft 100 along with corresponding track indications 1420, which indicate the respective track directions of the objects. In some examples, the objects may, for example, be color-coded to indicate the risk of conflict posed by a particular craft (e.g., red = high risk, green = low risk, etc.)

[0192] Returning to Figure 13, in some examples, information indicative of the conflict risk map and the conflict avoidance path 1410 is communicated to the VCS 1335 of the craft 100, along with information that characterizes the sea state. The VCS 1335 may then perform operations to cause the craft 100 to follow the conflict avoidance path 1410. In some examples, the VCS 1335 performs these operations automatically after receiving the conflict avoidance path 1410. In some examples, the VCS 1335 holds off on performing these operations until after receiving an indication from the pilot to do so (e.g., via the pilot user interface 1340). In this regard, in some examples, more than one conflict avoidance path 1410 may be generated, and the pilot may indicate to the VCS 1335 which one of the conflict avoidance paths 1410 should be followed.

[0193] For example, if the craft is airborne, the VCS 1335 may adjust one or more control surfaces such as the flaps 118, ailerons 120, elevators 126, rudders 128a, 128b, 128n, vertical stabilizer 122 to cause the craft to change its heading and/or altitude to follow the conflict avoidance path 1410. The VCS 1335 may control one of the propeller assemblies 116 to adjust the speed of the craft to follow the conflict avoidance path 1410.

[0194] If the craft is hydrofoil borne, the VCS 1335 may adjust one or more control surfaces, such as the rudders 128a, 128b, 128n or differentially control the speeds of one or more of the propeller assemblies 116 to induce yaw into the craft 100 and follow the conflict avoidance path 1410. The VCS 1335 may control one of the propeller assemblies 116 to adjust the speed of the craft 100 to cause the craft 100 to follow the conflict avoidance path 1410.

VI. Example Craft Operations

[0195] Figure 15 illustrates various obstacle avoidance operations 1500 performed by some examples of the craft 100. In some examples, the operations 1500 illustrated in the figure are implemented via instruction code that is executed by one or more processors of the control system 500 of the craft 100 that causes the control system 500 to control, alone or in cooperation with other subsystems of the craft 100, components of the craft 100 to perform these operations. Additionally, or alternatively, one or more of the operations can be implemented or controlled by dedicated hardware, such as via one or more application-specific integrated circuits (ASICs). Some aspects of the operations may be executed as a result of or in combination with inputs

received from an operator of the craft 100 or other subsystems of the craft 100. Other aspects of the operations may alternatively and/or additionally be executed automatically.

[0196] The operations at block 1505 involve determining one or more of the operating modes of the craft 100, the trajectory of the craft 100, and/or the intended path of the craft 100. For example, the craft 100 may be traveling along various predetermined paths or trajectories while maneuvering/transitioning between hull-borne, hydrofoil-borne, and airborne modes of operations. In some examples, the control system 500 uses sensor data received from a flight instrument system 524, an inertial navigation system (INS) 514, one or more altitude sensors, etc., to determine the specific heading, speed, altitude, etc. associated with these paths or trajectories.

[0197] In this regard, in some examples, when the craft is airborne, the control system 500 may determine the altitude of the craft based in part on sensor data provided by radar altimeters - 905a, 905b, which are capable of sensing distances of several hundred feet, and that have a relatively wide FOV 910a, 910b. When the craft 100 is lower than about 30 feet or when the craft 100 is hydrofoil borne, the control system 500 may determine the altitude of the craft 100 based in part on sensor data provided by ultrasonic sensors 905c, 905d, 905e, 905f, which can provide more precise distance measurements.

[0198] The operations at block 1510 involve the craft 100 using particular sensors to sense objects near the craft 100 and the corresponding trajectories of those objects. In some examples, the sensors used by the craft 100 to detect objects depend on the operating mode of the craft 100. In some examples, sensors that are not being relied upon (e.g., due to the operating mode) may be disabled, or sensor data from those sensors may be disregarded.

[0199] For example, when the craft 100 is hull-borne or hydrofoil-borne, the control system 500 may fuse together sensor data from one or more of the sensors/systems that facilitate above-water and below-water object detection to sense objects. For instance, the CDRC logic 1300 implemented by the control system 500 may fuse together sensor data from one or more of the forward-looking sensors 1005, rearward-looking sensors 1010, and side-looking sensors 1015 shown in Figure 10 to obtain a 360° FOV view of the above-water environment around the craft 100, along with one or more of the forward-looking sensors 1105 shown in Figure 11 that have a FOV below the water surface. In some examples, the craft 100 may include a periscope sensor 1020 that facilitates seeing objects 4-5 km out, and the control system 500 may cause the

periscope sensor 1020 to deploy when the craft 100 is moving relatively slowly and to retract before attempting to take off. Similarly, the control system 500 may cause the periscope sensor to deploy after the craft 100 lands and begins hydrofoil-borne and/or hull-borne maneuvering operations.

[0200] When the craft 100 is airborne, the control system 500 may fuse together sensor data from one or more of the sensors/systems that facilitate above-water detection to sense objects. For instance, the CDRC logic 1300 implemented by the control system 500 may fuse together sensor data from one or more of the forward-looking sensors 1005, rearward-looking sensors 1010, and side-looking sensors 1015 shown in Figure 10 and forgo using the sensors of Figure 11. In some examples, when the craft 100 is airborne, the control system 500 may rely primarily (or entirely) on a predetermined subset of the sensors, such as the forward-looking sensors 1005 to detect objects. In some examples, sensors such as those that provide a FOV of the below-water environment may be disabled, or sensor data from these sensors may be ignored or given lesser weight.

[0201] In some examples, as the craft 100 transitions from being airborne to being hydrofoil borne, the control system 500 may additionally start to rely on the side-looking sensors 1015 as the craft 100 descends. As the craft 100 transitions to becoming hydrofoil borne, the control system 500 may further rely on the rearward-looking sensors 1010 and the forward-looking sensors 1105 shown in Figure 11 that have a FOV below the water surface.

[0202] The operations at block 1515 involve the control system 500 determining, based on the current trajectory and intended path of the craft 100, and the corresponding trajectories of the detected objects, whether a potential conflict exists. If a potential conflict exists, then the operations at block 1520 and/or at block 1522 are performed.

[0203] The operations at block 1520 involve causing the craft 100 to communicate an indication of the potential conflict to the pilot. For example, an indication of the potential conflict may be communicated to a pilot-control user interface in the cockpit, as depicted in Figure 14.

[0204] The operations at block 1522 involve determining an alternative trajectory or path for the craft 100 to take to mitigate the chances of a conflict. For example, the CDRC logic 1300 may generate a conflict risk map that specifies potential collision zones. After determining the

conflict risk map, the CDRC logic 1300 may determine a conflict avoidance path 1410 for avoiding the potential conflict zones.

[0205] The operations at block 1525 involve causing the craft 100 to follow the alternative trajectory or path. For example, the CDRC logic 1300 may communicate the conflict risk map and the conflict avoidance path 1410 to the VCS 1335 of the craft 100. The VCS 1335 may then perform operations to cause the craft 100 to follow the conflict avoidance path 1410.

[0206] For example, if the craft is airborne, the VCS 1335 may adjust one or more control surfaces such as the flaps 118, ailerons 120, elevators 126, rudders 128a, 128b, 128n, vertical stabilizer 122 to cause the craft to change its heading and/or altitude to follow the conflict avoidance path 1410. The VCS 1335 may control one of the propeller assemblies 116 to adjust the speed of the craft to follow the conflict avoidance path 1410.

[0207] If the craft is hydrofoil borne, the VCS 1335 may adjust one or more control surfaces, such as the rudders 128a, 128b, 128n or differentially control the speeds of one or more of the propeller assemblies 116 to induce yaw into the craft and follow the conflict avoidance path 1410. The VCS 1335 may control one of the propeller assemblies 116 to adjust the speed of the craft to cause the craft 100 to follow the conflict avoidance path 1410.

[0208] Figure 16 illustrates example surface-piercing object identification operations 1600 performed by some examples of the craft 100. Some examples of these operations may be performed as part of the operations of block 1510, as described in Figure 15. In some examples, the operations 1600 illustrated in the figure are implemented via instruction code that is executed by one or more processors of the control system 500 of the craft 100 that causes the control system 500 to control, alone or in cooperation with other subsystems of the craft 100, components of the craft 100 to perform these operations. Additionally, or alternatively, one or more of the operations can be implemented or controlled by dedicated hardware, such as via one or more application-specific integrated circuits (ASICs). Some aspects of the operations may be executed as a result of or in combination with inputs received from an operator of the craft 100 or other subsystems of the craft 100. Other aspects of the operations may alternatively and/or additionally be executed automatically.

[0209] The operations at block 1605 involve detecting a first object or first object portion via one or more above-water-object sensors 1005, 1010, 1015 and a second object or second object portion via one or more below-water-object sensors 1105. For example, the control system 500

of the craft 100 may a) detect the first object via one or more of the forward-looking sensors 1005, rearward-looking sensors 1010, and side-looking sensors 1015 described in regards to Figure 10 that are configured to detect and monitor above-water objects and b) detect the second object via one or more of the below-water-object sensors 1105 described in regards to Figure 11 that have a FOV of the below-water scene in front of the craft 100 and that facilitate the detection and monitoring of objects that are below the surface of the water.

[0210] The operations at block 1610 involve determining whether the first object and the second object correspond to the same object. In some examples, this determination or inference is made by the ML logic described above that is implemented by some examples of the control system 500. For example, the ML logic may be trained to determine that a first object detected by one or more of the above-water-object sensors 1005, 1010, 1015 and a second object detected by one or more of the below-water-object sensors 1105 are the same object when the first object and the second object are at the same general location relative to the craft (e.g., both objects are directly in front of the craft 100, one the same side of the craft 100, etc., and are at about the same distance from the craft 100). The ML logic may alternatively or additionally be trained to determine that the first object and the second object are the same if the two objects move in the same direction and speed relative to the craft 100.

[0211] If, at block 1610, the first object and the second object are determined to correspond to the same object, then the operations at block 1615 are performed. These operations involve determining that the first object and the second object correspond to a surface-piercing object. In some examples, after determining that the first object and the second object correspond to a surface-piercing object, the type of surface-piercing object is determined. For example, the ML logic described may be further trained to determine the type of object based on factors such as the size and speed of the object, the ratio of the above-water portion of the object to the below-water portion of the object, and the shapes of the respective portions. For example, an object that is determined to be relatively stationary or slow-moving may, based on its shape, be assessed to be a slow or stationary object, such as an iceberg, buoy, partially submerged container, log, etc. An object that is determined to be fast-moving and/or moving erratically may, based on its shape, be assessed to be a fast-moving and/or erratically moving object, such as a swimmer, a breaching whale, a dolphin, etc.

[0212] If, at block 1610, the first object and the second object are determined to correspond to different objects, then the operations at block 1620 are performed. These operations involve determining the type of the first object and the type of the second object. For example, the ML logic may be further trained to determine the type of object based on factors such as the size, speed, and shape of the object.

[0213] After the object type or types are determined, operations such as those described in regard to block 1510 of Figure 15 are performed to determine whether a potential conflict exists between the craft 100 and the identified objects. For example, the control system 500 may determine, based on the current trajectory and the intended path of the craft 100, and the corresponding trajectories of the detected object(s), whether a potential conflict exists. If a potential conflict exists, an indication of the potential conflict may be communicated to the pilot via a pilot-control user interface in the cockpit, as depicted in Figure 14. In some examples, an alternative trajectory or path for the craft 100 to take to mitigate the chances of a conflict may be determined and the craft 100 may be operated to follow the alternative trajectory or path.

VII. Additional Example Embodiments

[0214] In addition the embodiments and variations thereon described above, additional embodiments and variations are outlined below as further non-limiting examples of various aspects of the disclosed features and functionality and combinations thereof. Persons of skill in the art will recognize that any of the features and/or functions of the example embodiments disclosed in this section may be combined with any of the other features and/or functions disclosed in this section and anywhere else within the present disclosure in any suitable manner.

[0215] **Example 1:** A craft comprising: (i) a hull; (ii) a wing coupled to the hull; (iii) one or more first sensors, wherein at least one of the one or more first sensors is affixed to the craft at a position forward of the wing, and at least one the one or more first sensors is affixed to the wing; (iv) one or more second sensors, wherein at least one of the one or more second sensors is affixed to a bottom surface of the wing; and (v) data storage having instruction code stored thereon that, when executed by one or more processors of the craft, causes the craft to: (a) travel according to a predetermined path relative to a water surface; (b) receive (b-1) first sensor data via one or more first sensors and (b-2) second sensor data via the one or more second sensors; (c) determine, based at least in part on the first sensor data, a respective location and a respective

trajectory of each of one or more above-water objects; (d) determine, based at least in part on the second sensor data, a height of the craft above a nominal level of the water surface; (e) determine, based on (e-1) the determined respective location and trajectory of each of the one or more above-water objects, (e-2) the determined height of the craft above the water surface, (e-3) the predetermined path, and (e-4) a location of the craft, whether at least one of the one or more above-water objects will come within a threshold distance of the craft; and (f) when it is determined that at least one of the one or more above-water objects will come within the threshold distance of the craft, (f-1) determine a modified path and (f-2) cause the craft to travel according to the modified path; and (g) when it is determined that none of the one or more above-water objects will come within the threshold distance of the craft, cause the craft to continue to travel according to the predetermined path.

[0216] Example 2: The craft according to Example 1 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, further comprising one or more hydrofoil assemblies that extend from a lower surface of the hull and that facilitate hydrofoil-borne operation of the craft, wherein the instruction code causes the craft to: (i) when the craft is airborne, determine a distance between the craft and the water surface based on second sensor data associated with a first subset of the one or more second sensors and forgo determining the distance between the craft and the water surface based on second sensor data associated with a second subset of the one or more second sensors; and (ii) when the craft is hydrofoil borne, determine the distance between the craft and the water surface based on second sensor data associated with the second subset of the one or more second sensors and forgo determining the distance between the craft and the water surface based on second sensor data associated with the first subset of the one or more second sensors.

[0217] Example 3: The craft according to Example 2 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein at least a subset of the one or more of the second sensors are positioned so that the one or more hydrofoil assemblies are not in respective fields of view of the subset of the one or more of the second sensors.

[0218] Example 4: The craft according to Example 2 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the first subset of the one or more second sensors correspond to radar altimeters, and the second subset of the one or more second sensors correspond to ultrasonic sensors.

[0219] **Example 5:** The craft according to Example 1 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the one or more first sensors correspond to one or more: electro-optical (EO) color cameras, infrared (IR) cameras, radar systems, light detection and ranging (LIDAR) systems, ultrasonic transducers, passive RF systems, and acoustic systems.

[0220] **Example 6:** The craft according to Example 1 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the one or more first sensors comprise a first sensor at a nose of the craft that has a field of view (FOV) of a scene in front of the craft, a second sensor positioned towards a rear end of the craft that has FOV of a scene behind the craft, a third sensor and a fourth sensor positioned on respective port and starboard sides of the craft that have FOVs of scenes left and right of the craft, respectively, to provide a 360° FOV around the craft.

[0221] **Example 7:** The craft according to Example 1 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, further comprising one or more third sensors affixed to a lower section of the craft, wherein the instruction code causes the craft to: (a) receive third sensor data via the one or more third sensors; (b) determine, based on the third sensor data, respective locations of one or more below-water objects; (c) determine whether one or more of the below-water objects will come within a threshold distance of the craft based on (c-1) the determined respective locations of the one or more below-water objects, (c-2) the location of the craft, and (c-3) the predetermined path of the craft; (d) when it is determined that at least one of the one or more below-water objects will come within the threshold distance of the craft, (d-1) determine a modified path and (d-2) cause the craft to travel according to the modified path; and (e) when it is determined that none of the one or more below-water objects will come within the threshold distance of the craft, cause the craft to continue to travel according to the predetermined path.

[0222] **Example 8:** The craft according to Example 7 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the instruction code causes the craft to determine, based on the first sensor data and the third sensor data, a particular above-water object and a particular below-water object to correspond to a same object.

[0223] Example 9: The craft according to Example 7 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein at least one of the one or more third sensors is affixed to a bottom of the hull.

[0224] Example 10: The craft according to Example 7 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, further comprising a front hydrofoil assembly and a rear hydrofoil assembly that each extend from a lower surface of the hull and that facilitate hydrofoil borne operation of the craft, wherein at least one of the one or more third sensors is positioned along a front edge of a hydrofoil of the front hydrofoil assembly.

[0225] Example 11: The craft according to Example 1 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, further comprising: (i) one or more hydrofoil assemblies that extend from a lower surface of the hull and that facilitate hydrofoil-borne operation of the craft; (ii) one or more third sensors; and (iii) wherein the instruction code causes the craft to: (a) receive third sensor data associated via the one or more third sensors; (b) determine, based at least in part on the third sensor data, whether the one or more hydrofoil assemblies are operating in a first state; and (c) when the one or more hydrofoil assemblies are determined to be operating in the first state, cause the craft to perform an operation to cause the one or more hydrofoil assemblies to operate in a second state.

[0226] Example 12: The craft according to Example 11 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the first state corresponds to the one or more hydrofoil assemblies not operating nominally and the second state corresponds to the one or more hydrofoil assemblies operating nominally.

[0227] Example 13: The craft according to Example 1 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein a particular first sensor of the one of the one or more first sensors is configured to selectively extend and retract from an upper surface of the craft, and wherein the instruction code causes the craft to: (i) while the craft is airborne, maintain the particular first sensor in a retracted state; (ii) determine that the craft has contacted water; and (iii) after determining that the craft has contacted the water, cause the particular first sensor to extend from the craft.

[0228] Example 14: The craft according to Example 1 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, further comprising a plurality of propellers distributed across the wing, wherein a particular first sensor is a forward sensing propeller and is

positioned behind a particular propeller of the plurality of propellers, and wherein the instruction code causes the craft to: (i) filter first sensor data associated with the particular first sensor so that propeller blades of the particular propeller are not sensed as above-water objects.

[0229] Example 15: The craft according to Example 1 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the predetermined path and the modified path correspond to paths that craft follows when the craft is airborne.

[0230] Example 16: The craft according to Example 1 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the predetermined path and the modified path correspond to paths that craft follows when the craft is hydrofoil-borne.

[0231] Example 17: The craft according to Example 1 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, when determining the modified path and causing the craft to travel according to the modified path comprises: (i) generating a conflict risk map that specifies potential collision zones between the craft and the one or more above-water objects; (ii) generating a conflict avoidance path for avoiding potential conflict zones; and (iii) communicating the generate a conflict risk map and the conflict avoidance path to a vehicle control system (VCS) is configured to operate one or more components of the craft to cause the craft to follow the conflict avoidance path.

[0232] Example 18: The craft according to Example 17 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the instruction code causes the craft to: (i) when the craft is airborne, cause the VCS to adjust one or more control surfaces of one or more of flaps, ailerons, elevators, rudders, and vertical stabilizers of the craft to cause the craft to change its heading and altitude to follow the conflict avoidance path; and (ii) when the craft is hydrofoil borne, cause the VCS to adjust one or more control surfaces of rudders of the craft or differentially control respective speeds of one or more of propeller assemblies of the craft to induce yaw into the craft to cause the cause the craft to follow the conflict avoidance path.

[0233] Example 19: The craft according to Example 1 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the instruction code causes the craft to: (i) generate conflict risk map graphical representation that indicates one or more objects detected by one or more sensors of the craft along with corresponding track indications of the

one or more objects; and (ii) communicate the generated conflict risk map graphical representation to a user interface of the craft.

[0234] Example 20: The craft according to Example 1 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the instruction code causes the craft to: (i) time-synchronize sensor data generated by the one or more first sensors and the one or more second sensors; (ii) normalize values specified in the time-synchronize sensor data, and (iii) filter the normalized values to remove values that exceed one or more expected ranges.

[0235] Example 21: A craft comprising: (i) a hull; (ii) a wing coupled to the hull; (iii) one or more first sensors, wherein at least one of the one or more first sensors is affixed to the craft at a position forward of the wing; (iv) one or more second sensors, wherein at least one of the one or more second sensors is affixed to the craft at a position below the wing; and (v) data storage having instruction code stored thereon that, when executed by one or more processors of the craft, causes the craft to: (a) receive first sensor data from at least one of the first one or more sensors, wherein the first sensor data specifies a first portion of an object; (b) receive second sensor data from at least one of the second one or more sensors, wherein the second sensor data specifies a second portion of the object; (c) determine, based on at least the received first sensor data and the received second sensor data, that the first portion of the object and the second portion of the object correspond to the same object; and (e) after determining that the first portion of the object and the second portion of the object correspond to the same object, provide an indication of the object via an operator interface of the craft.

[0236] Example 22: The craft according to Example 21 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the one or more first sensors comprise a sensor that facilitates above-water-object sensing.

[0237] Example 23: The craft according to Example 21 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the one or more second sensors comprise a sensor that facilitates below-water-object sensing.

[0238] Example 24: The craft according to Example 21 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, further comprising one or more hydrofoils, wherein the one or more second sensors comprise a sensor affixed to at least one of the one or more hydrofoils.

[0239] **Example 25:** The craft according to Example 21 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein determining that the first portion of the object and the second portion of the object correspond to the same object comprises determining that the object is a surface-piercing object.

[0240] **Example 26:** The craft according to Example 21 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the instruction code is further executable to cause the craft to: (a) travel according to a predetermined path relative to a water surface; (b) determine, based at least in part on the received first sensor data and the received second sensor data, a respective location of the object; (c) determine whether the object will come within a threshold distance of the craft based on (c-1) the determined location the object, (c-2) the predetermined path, and (c-3) a location of the craft; (d) when it is determined that the object will come within the threshold distance of the craft, (d-1) determine a modified path and (d-2) cause the craft to travel according to the modified path; and (e) when it is determined that the object will not come within the threshold distance of the craft, cause the craft to continue to travel according to the predetermined path.

[0241] **Example 27:** A craft comprising: (A) a hull; (B) a wing coupled to the hull; (C) one or more first sensors, wherein at least one of the one or more first sensors is affixed to the craft at a position below the wing; (D) one or more second sensors, wherein at least one of the one or more second sensors is affixed to the craft at a position below the wing; and (E) data storage having instruction code stored thereon that, when executed by one or more processors of the craft, causes the craft to: (i) at a first time while traveling in contact with water, (a) receive first sensor data from the at least one of the one or more first sensors, and (b) determine a first height of the craft based on the received first sensor data without use of second sensor data received from the at least one of the one or more second sensors; (ii) at a second time, (a) receive first sensor data from the at least one of the one or more first sensors, (b) receive second sensor data from the at least one of the second or more sensors, and (c) determine a second height of the craft based on the received first sensor data and the received second sensor data; (iii) at a third time while traveling without contact with the water, (a) receive second sensor data from the at least one of the one or more second sensors, and (b) determine a third height of the craft based on the received second sensor data without use of first sensor data received from the at least one of the one or more first sensors.

[0242] **Example 28:** The craft according to Example 27 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the at least one of the one or more first sensors comprises an ultrasonic sensor.

[0243] **Example 29:** The craft according to Example 27 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the at least one of the one or more second sensors comprises a radar altimeter.

[0244] **Example 30:** The craft according to Example 27 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein at the second time the craft is traveling in contact with the water.

[0245] **Example 31:** The craft according to Example 27 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein at the second time the craft is traveling without contact with the water.

[0246] **Example 32:** The craft according to Example 27 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, further comprising data storage having instruction code stored thereon that, when executed by one or more processors of the craft, causes the craft to after receiving the first sensor data and before receiving the fourth sensor data, execute a craft takeoff procedure.

[0247] **Example 33:** The craft according to Example 27 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, further comprising one or more third sensors that facilitate above-water object sensing, wherein the instruction code is further executable to cause the craft to: (a) travel according to a predetermined path relative to a water surface; (b) determine, based at least in part on third sensor data received from at least one of the one or more third sensors, a respective location of each of one or more above-water objects; (c) determine whether at least one of the one or more above-water objects will come within a threshold distance of the craft based on (1) the determined respective location of each of the one or more above-water objects, (2) the predetermined path, and (3) a location of the craft; (d) when it is determined that at least one of the one or more above-water objects will come within the threshold distance of the craft, (1) determine a modified path and (2) cause the craft to travel according to the modified path; and (e) when it is determined that none of the one or more above-water objects will come within the threshold distance of the craft, cause the craft to continue to travel according to the predetermined path.

[0248] Example 34: The craft according to Example 33 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the third sensor data specifies a first portion of an object, wherein the craft further comprises one or more fourth sensors that facilitate below-water object sensing, and wherein the instruction code is further executable to cause the craft to: (i) receive fourth sensor data from at least one of the one or more fourth sensors, wherein the fourth sensor data specifies a second portion of the object; (ii) determine, based on at least the received third sensor data and the received fourth sensor data, that the first portion of the object and the second portion of the object correspond to the same object; and (iii) after determining that the first portion of the object and the second portion of the object correspond to the same object, provide an indication of the object via an operator interface of the craft.

[0249] Example 35: A craft comprising: (i) a hull; (ii) a wing coupled to the hull; (iii) one or more first altitude sensors configured to determine a first distance between the craft and a water surface when the craft is at a first height relative to the water surface; (iv) one or more second altitude sensors configured to determine a second distance between the craft and the water surface when the craft is at a second height relative to the water surface, the second height lower than the first height, wherein the one or more second altitude sensors are different from the one or more first altitude sensors; and (v) data storage having instruction code stored thereon that, when executed by one or more processors of the craft, causes the craft to: (a) receive, when the craft is at the first height, first altitude sensor data from the one or more first altitude sensors; (b) determine, based on at least the first altitude sensor data, the first distance between the craft and the water surface; (c) receive, when the craft is at the second height, second altitude sensor data from the one or more second altitude sensors; and (d) determine, based on the second altitude sensor data, the second distance between the craft and the water surface.

[0250] Example 36: The craft of Example 35 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the first altitude sensors comprise a radar altimeter, and the second altitude sensors comprise an ultrasonic sensor.

[0251] Example 37: The craft of Example 35 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the first height is associated with a wing-borne mode of operation, and the second height is associated with a hydrofoil-borne mode of operation.

[0252] Example 38: The craft of Example 35 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the instruction code further causes the craft to determine a weighted average of altitude measurements from the first altitude sensors and the second altitude sensors.

[0253] Example 39: The craft of Example 35 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the instruction code further causes the craft to forgo using altitude measurements from the second altitude sensors for determining the first distance when the craft is above a predetermined height.

[0254] Example 40: The craft of Example 35 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the instruction code further causes the craft to transition from determining the distance based on the first altitude sensor data and not based on the second altitude sensor data to determining the distance based on the second altitude sensor data when the distance determined based on the first altitude sensor data is below a threshold distance.

[0255] Example 41: The craft of Example 35 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the instruction code further causes the craft to: (i) receive first altitude sensor data from the one or more first altitude sensors; (ii) receive second altitude sensor data from the one or more second altitude sensors; and (iii) determine the first distance between the craft and the water surface based on a weighted average of the first altitude sensor data and the second altitude sensor data.

[0256] Example 42: The craft of Example 41 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein a weighting of the first altitude sensor data is greater than a weighting of the second altitude sensor data when the craft is at the first height.

[0257] Example 43: The craft of Example 41 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein a weighting of the second altitude sensor data is greater than a weighting of the first altitude sensor data when the craft is at the second height.

[0258] Example 44: The craft of Example 35 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the craft comprises one or more hydrofoil assemblies, and wherein at least a subset of the second altitude sensors are positioned so that the one or more hydrofoil assemblies are not in respective fields of view of the subset of the second altitude sensors.

[0259] Example 45: A craft comprising: (i) a hull; (ii) at least one hydrofoil assembly coupled to the hull, the at least one hydrofoil assembly comprising at least one hydrofoil; (iii) at least one below-water-object sensor coupled to a forward-facing surface of the at least one hydrofoil; and (iv) data storage having instruction code stored thereon that, when executed by one or more processors of the craft, causes the craft to: (a) receive below-water-object sensor data from the at least one below-water-object sensor; and (b) determine a presence of an object positioned below a water surface and in front of the craft based on the received below-water-object sensor data.

[0260] Example 46: The craft of Example 45 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the at least one below-water-object sensor is coupled to a leading edge of the at least one hydrofoil.

[0261] Example 47: The craft of Example 45 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the at least one below-water-object sensor is one of: (i) a sonar sensor; (ii) an electro-optical (EO) camera; (iii) a gravitational sensor; and (iv) an electromagnetic sensor.

[0262] Example 48: The craft of Example 45 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the at least one below-water-object sensor is positioned to have a field of view of approximately 90 degrees.

[0263] Example 49: The craft of Example 45 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, further comprising a plurality of below-water-object sensors, wherein the plurality of below-water-object sensors are positioned along a length of the leading edge of the at least one hydrofoil.

[0264] Example 50: The craft of Example 49 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein sensor data received from the plurality of below-water-object sensors is combined to provide a 360-degree view of an area below the craft.

[0265] Example 51: The craft of Example 45 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the craft is further configured to receive above-water-object sensor data from at least one above-water-object sensor positioned on the craft, and to determine a presence of an object at least partially positioned above a water surface based on the above-water-object sensor data.

[0266] Example 52: The craft of Example 51 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the craft is further configured to determine that an object detected by the at least one below-water-object sensor and an object detected by the at least one above-water-object sensor correspond to the same object.

[0267] Example 53: The craft of Example 52 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the same object is a surface-piercing object.

[0268] Example 54: The craft of Example 45 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, further comprising a wing coupled to the hull, wherein the at least one hydrofoil assembly is configured to move between a deployed position, in which the at least one hydrofoil extends below the hull, and a retracted position, in which the at least one hydrofoil is positioned adjacent to the hull.

[0269] Example 55: A craft comprising: (i) a hull; (ii) at least one hydrofoil assembly coupled to the hull, the at least one hydrofoil assembly comprising at least one hydrofoil; (iii) at least one sensor positioned on the craft, the at least one sensor configured to sense a portion of the craft; and (iv) data storage having instruction code stored thereon that, when executed by one or more processors of the craft, causes the craft to: (a) receive sensor data from the at least one sensor; and (b) determine, based on the received sensor data, each of: (1) a presence of an object positioned at least partially above a water surface; (2) a presence of an object positioned at least partially below a water surface; and (3) an operational characteristic of the portion of the craft.

[0270] Example 56: The craft of Example 55 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the at least one sensor is positioned on an underside of the hull.

[0271] Example 57: The craft of Example 55 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the portion of the craft comprises at least one hydrofoil.

[0272] Example 58: The craft of Example 57 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the operational characteristic comprises at least one of: (a) a deflection angle of a control surface on the at least one hydrofoil; (b) an extension amount of the at least one hydrofoil; and (c) a presence of debris on the at least one hydrofoil.

[0273] Example 59: The craft of Example 55 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the at least one sensor comprises at least one of: (a) a sonar sensor; (b) an electro-optical (EO) camera; and (c) a laser-based sensor.

[0274] Example 60: The craft of Example 55 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, further comprising at least one actuator coupled to the portion of the craft, wherein the craft is further configured to receive actuator data from the at least one actuator, and wherein determining the operational characteristic is further based on the received actuator data.

[0275] Example 61: The craft of Example 60 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the at least one actuator is configured to control at least one of: (a) a deflection angle of a control surface on the at least one hydrofoil; and (b) an extension amount of the at least one hydrofoil.

[0276] Example 62: The craft of Example 55 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the at least one sensor is further configured to sense a scene in front of the craft, wherein determining the presence of the object positioned at least partially above the water surface is based on sensor data associated with the scene in front of the craft.

[0277] Example 63: The craft of Example 62 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the at least one sensor is further configured to sense a scene below the water surface and in front of the craft, wherein determining the presence of the object positioned at least partially below the water surface is based on sensor data associated with the scene below the water surface.

[0278] Example 64: The craft of Example 55 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the portion of the craft comprises a wing.

[0279] Example 65: A craft comprising: (i) a hull; (ii) a wing coupled to the hull; (iii) a plurality of sensors; and (iv) data storage having instruction code stored thereon that, when executed by one or more processors of the craft, causes the craft to: (a) receive sensor data from the plurality of object sensors; (b) determine, based on the received sensor data, a presence of one or more objects positioned proximate to the craft; (c) determine a trajectory for each of the one or more objects; (d) generate a conflict risk assessment that indicates a risk of the craft colliding with each of the one or more objects; (e) determine, based on the conflict risk

assessment, an alternative trajectory for the craft to follow; and (f) execute the determined alternative trajectory for the craft.

[0280] Example 66: The craft of Example 65 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the plurality of object sensors comprise a first sensor at a nose of the craft that has a field of view (FOV) of a scene in front of the craft, a second sensor positioned towards a rear end of the craft that has an FOV of a scene behind the craft, a third sensor and a fourth sensor positioned on respective port and starboard sides of the craft that have FOVs of scenes left and right of the craft, respectively.

[0281] Example 67: The craft of Example 65 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the alternative trajectory comprises a path that avoids a region in which a risk of collision is indicated by the generated conflict risk assessment.

[0282] Example 68: The craft of Example 65 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the craft is further configured to output a visual representation of the conflict risk assessment via a user interface of the craft.

[0283] Example 69: The craft of Example 65 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, further comprising a control system configured to control movement of the craft, wherein the craft is further configured to communicate the determined alternative trajectory to the control system.

[0284] Example 70: The craft of Example 69 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the control system is configured to cause the craft to execute the alternative trajectory.

[0285] Example 71: The craft of Example 65 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the plurality of sensors comprise at least one sensor configured to sense objects positioned at least partially above a surface of water, and at least one sensor configured to sense objects at least partially positioned below a surface of water.

[0286] Example 72: The craft of Example 71 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein at least one of the at least one sensor configured to sense objects at least partially positioned below the surface of water is coupled to a hydrofoil of the craft.

[0287] Example 73: The craft of Example 65 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the craft is configured to determine the trajectory for each of the one or more objects based on a change in a position of a detected object over time.

[0288] Example 74: The craft of Example 65 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein generating the conflict risk assessment comprises performing operations to estimate a likelihood of the craft colliding with each of the one or more objects based on a combination of (a) the determined trajectories for the one or more objects and (b) a current trajectory of the craft.

[0289] Example 75: The craft of Example 65 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the plurality of sensors comprise at least one sensor selected from the group consisting of: (a) an electro-optical (EO) color camera; (b) an infrared (IR) camera; and (c) a radar system.

[0290] Example 76: The craft of Example 65 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein at least one of the plurality of sensors is positioned on a surface of the craft selected from the group consisting of: (a) a nose of the craft; (b) a canopy of the craft; (c) a box tail of the craft; (d) a wing of the craft; (e) an upper surface of the hull; and (f) a lower surface of the hull.

[0291] Example 77: The craft of Example 76 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein at least one of the plurality of sensors is positioned on the wing of the craft, and the at least one sensor is positioned at a location on the wing that, in normal operation of the craft, is outside of a field of spray from propeller assemblies coupled to the wing.

[0292] Example 78: The craft of Example 65 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein at least one of the plurality of sensors is positioned behind a propeller assembly coupled to the wing, and the craft is configured to filter object sensor data associated with the at least one sensor so that propeller blades of the propeller assembly are not sensed as objects.

[0293] Example 79: The craft of Example 65 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein at least one of the plurality of sensors is configured to selectively extend and retract from the craft.

[0294] Example 80: The craft of Example 65 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the conflict risk assessment comprises a conflict risk map.

[0295] Example 81: A craft comprising: (i) a hull; (ii) a wing coupled to the hull; (iii) a plurality of sensors coupled to the craft; (iv) one or more processors; and (v) data storage having instruction code stored thereon that, when executed by the one or more processors, causes the craft to: (a) receive sensor data from the plurality of sensors, the sensor data indicating information associated with an environment of the craft; (b) characterize, based on the sensor data, a sea state associated with a water surface in the environment, the sea state comprising at least one of a current speed of the water surface, an average wave height of the water surface, a peak wave height of the water surface, and a wave frequency of the water surface; (c) identify, based on the sensor data, a plurality of objects in the environment; (d) track, over time, a location of each of the plurality of objects; (e) associate each of the plurality of objects with a corresponding track; (f) determine a confidence score associated with each of the plurality of objects and the corresponding track, the confidence score specifying a confidence level associated with a determination that the object is following the corresponding track; (g) select, from the plurality of objects, a subset of objects having a confidence score that exceeds a threshold amount; and (h) output an indication of the characterized sea state and an indication of the subset of objects and the corresponding tracks.

[0296] Example 82: The craft of Example 81 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein characterizing the sea state comprises determining a wave direction of the water surface.

[0297] Example 83: The craft of Example 81 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein outputting the indication of the characterized sea state comprises outputting the indication of the characterized sea state to a vehicle control system of the craft.

[0298] Example 84: The craft of Example 81 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein tracking, over time, the location of each of the plurality of objects comprises determining whether an object indicated by the sensor data is moving along a path, and associating the object with the path if it is determined that the object is moving along the path.

[0299] Example 85: The craft of Example 84 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein tracking, over time, the location of each of the plurality of objects further comprises comparing a location of an object in the subset of objects with a location of a known object to assess whether the object in the subset of objects is stationary.

[0300] Example 86: The craft of Example 85 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein tracking, over time, the location of each of the plurality of objects further comprises, if it is assessed that the object in the subset of objects is stationary, removing the object in the subset of objects from the subset of objects.

[0301] Example 87: The craft of Example 81 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein associating each of the plurality of objects with a corresponding track comprises comparing tracks of a first object and a second object to identify the first object and the second object as being the same object.

[0302] Example 88: The craft of Example 87 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein associating each of the plurality of objects with a corresponding track further comprises, if the first object and the second object are identified as being the same object, merging object data associated with the first object and the second object.

[0303] Example 89: The craft of Example 81 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein outputting the indication of the characterized sea state and the indication of the subset of objects and the corresponding tracks comprises outputting the indication of the characterized sea state and the indication of the subset of objects and the corresponding tracks to a conflict detection and resolution system of the craft.

[0304] Example 90: The craft of Example 81 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, further comprising a human machine interface, wherein outputting the indication of the subset of objects and the corresponding tracks comprises outputting the indication of the subset of objects and the corresponding tracks to the human machine interface.

[0305] Example 91: The craft of Example 90 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the vehicle control system is configured to, upon receiving the indication of the characterized sea state and the indication of the subset of

objects and the corresponding tracks, select from a plurality of control actions a control action to perform, the plurality of control actions comprising at least one of: (i) adjusting a speed of the craft; (ii) adjusting an altitude of the craft; and (iii) adjusting a heading of the craft.

[0306] Example 92: The craft of Example 91 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the vehicle control system is further configured to, after selecting the control action to perform, operate at least one component of the craft to perform the selected control action.

[0307] Example 93: The craft of Example 92 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein operating the at least one component of the craft comprises operating at least one of: (i) a propulsion system of the craft; (ii) an aerodynamic control surface of the craft; and (iii) a hydrofoil of the craft.

[0308] Example 94: The craft of Example 81 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein at least one of the plurality of sensors comprises a forward-looking sensor configured to sense an object in front of the craft.

[0309] Example 95: The craft of Example 94 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the plurality of sensors further comprises at least one of a rearward-looking sensor configured to sense an object behind the craft, and a side-looking sensor configured to sense an object to a side of the craft.

[0310] Example 96: The craft of Example 81 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein at least one of the plurality of sensors comprises a below-water object sensor configured to sense an object that is at least partially below a surface of a body of water.

[0311] Example 97: The craft of Example 96 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the below-water object sensor is located on at least one of a hydrofoil of the craft and a hull of the craft.

[0312] Example 98: The craft of Example 97 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the craft is further configured to determine, based at least in part on the sensor data received from at least one of the plurality of sensors, that a first portion of an object is detected at least partially above the surface of the body of water and a second portion of the object is detected at least partially below the surface of the body of water.

[0313] Example 99: The craft of Example 98 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the craft is further configured to, upon determining that the first portion of the object and the second portion of the object correspond to the same object, determine that the object is a surface-piercing object.

[0314] Example 100: The craft of Example 81 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the plurality of objects comprises at least one of an above-water object and a below-water object.

[0315] Example 101: A wing-in-ground effect craft comprising: (i) a hull; (ii) a wing coupled to the hull; (iii) a first set of sensors configured to sense an environment around the craft when the craft is in a first operational mode; and (iv) a second set of sensors configured to sense the environment around the craft when the craft is in a second operational mode different from the first operational mode, wherein the first operational mode is different from the second operational mode, and wherein the first set of sensors and the second set of sensors (a) comprise at least one different sensor and (b) comprise at least one same sensor.

[0316] Example 102: The craft of Example 101 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the first operational mode and the second operational mode are selected from the group consisting of: hull-borne mode, hydrofoil-borne mode, and airborne mode.

[0317] Example 103: The craft of Example 101 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the first set of sensors is configured to sense objects within a first detection range when the craft is in the first operational mode.

[0318] Example 104: The craft of Example 103 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the second set of sensors is configured to sense objects within a second detection range greater than the first detection range when the craft is in the second operational mode.

[0319] Example 105: The craft of Example 104 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the second set of sensors comprises at least one forward-looking sensor.

[0320] Example 106: The craft of Example 101 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the first set of sensors is configured to sense objects within a first field of view when the craft is in the first operational mode.

[0321] Example 107: The craft of Example 106 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the second set of sensors is configured to sense objects within a second field of view narrower than the first field of view when the craft is in the second operational mode.

[0322] Example 108: The craft of Example 101 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein the first set of sensors comprises a first number of sensors, and wherein the second set of sensors comprises a second number of sensors less than the first number of sensors.

[0323] Example 109: The craft of Example 101 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, wherein at least one sensor of the first set of sensors and at least one sensor of the second set of sensors is selected from the group consisting of: an electro-optical (EO) color camera, an infrared (IR) camera, a radar system, a light detection and ranging (LIDAR) system, an ultrasonic transducer, a passive RF system, and an acoustic system.

[0324] Example 110: The craft of Example 101 and/or any other Example(s) in this section or any other embodiment(s) disclosed herein, further comprising a controller configured to: (i) determine an operational mode of the craft; (ii) activate one of the first and second sets of sensors based on the operational mode; and (iii) use sensor data from the activated set of sensors to determine locations of objects around the craft.

VIII. Conclusions

[0325] While the systems and methods of operation have been described with reference to certain examples, it will be understood by those skilled in the art that various changes can be made, and equivalents can be substituted without departing from the scope of the claims. Therefore, it is intended that the present methods and systems not be limited to the particular examples disclosed, but that the disclosed methods and systems include all embodiments falling within the scope of the appended claims.

CLAIMS

What is claimed is:

1. A craft comprising:

a hull;

a wing coupled to the hull;

one or more first sensors, wherein at least one of the one or more first sensors is affixed to the craft at a position forward of the wing, and at least one the one or more first sensors is affixed to the wing;

one or more second sensors, wherein at least one of the one or more second sensors is affixed to a bottom surface of the wing; and

data storage having instruction code stored thereon that, when executed by one or more processors of the craft, causes the craft to:

travel according to a predetermined path relative to a water surface;

receive (1) first sensor data via one or more first sensors and (2) second sensor data via the one or more second sensors;

determine, based at least in part on the first sensor data, a respective location and a respective trajectory of each of one or more above-water objects;

determine, based at least in part on the second sensor data, a height of the craft above a nominal level of the water surface;

determine, based on (1) the determined respective location and trajectory of each of the one or more above-water objects, (2) the determined height of the craft above the water surface, (3) the predetermined path, and (4) a location of the craft, whether at least one of the one or more above-water objects will come within a threshold distance of the craft; and

when it is determined that at least one of the one or more above-water objects will come within the threshold distance of the craft, (1) determine a modified path and (2) cause the craft to travel according to the modified path; and

when it is determined that none of the one or more above-water objects will come within the threshold distance of the craft, cause the craft to continue to travel according to the predetermined path.

2. The craft of claim 1, further comprising:
one or more hydrofoil assemblies that extend from a lower surface of the hull and that facilitate hydrofoil-borne operation of the craft, wherein the instruction code causes the craft to:
when the craft is airborne, determine a distance between the craft and the water surface based on second sensor data associated with a first subset of the one or more second sensors and forgo determining the distance between the craft and the water surface based on second sensor data associated with a second subset of the one or more second sensors; and
when the craft is hydrofoil borne, determine the distance between the craft and the water surface based on second sensor data associated with the second subset of the one or more second sensors and forgo determining the distance between the craft and the water surface based on second sensor data associated with the first subset of the one or more second sensors.
3. The craft of claim 2, wherein at least a subset of the one or more of the second sensors are positioned so that the one or more hydrofoil assemblies are not in respective fields of view of the subset of the one or more of the second sensors.
4. The craft of claim 2, wherein the first subset of the one or more second sensors correspond to radar altimeters, and the second subset of the one or more second sensors correspond to ultrasonic sensors.
5. The craft of claim 1, wherein the one or more first sensors correspond to one or more: electro-optical (EO) color cameras, infrared (IR) cameras, radar systems, light detection and ranging (LIDAR) systems, ultrasonic transducers, passive RF systems, and acoustic systems.
6. The craft of claim 1, wherein the one or more first sensors comprise a first sensor at a nose of the craft that has a field of view (FOV) of a scene in front of the craft, a second sensor positioned towards a rear end of the craft that has FOV of a scene behind the craft, a third sensor and a fourth sensor positioned on respective port and starboard sides of the craft that have FOVs of scenes left and right of the craft, respectively, to provide a 360° FOV around the craft.
7. The craft of claim 1, further comprising one or more third sensors affixed to a lower section of the craft, wherein the instruction code causes the craft to:
receive third sensor data via the one or more third sensors;

determine, based on the third sensor data, respective locations of one or more below-water objects;

determine, based on (1) the determined respective locations of the one or more below-water objects, (2) the location of the craft, and (3) the predetermined path of the craft, whether one or more of the below-water objects will come within a threshold distance of the craft;

when it is determined that at least one of the one or more below-water objects will come within the threshold distance of the craft, (1) determine a modified path and (2) cause the craft to travel according to the modified path;

when it is determined that none of the one or more below-water objects will come within the threshold distance of the craft, cause the craft to continue to travel according to the predetermined path.

8. The craft of claim 7, wherein the instruction code causes the craft to:
determine, based on the first sensor data and the third sensor data, a particular above-water object and a particular below-water object to correspond to a same object.

9. The craft of claim 7, wherein at least one of the one or more third sensors is affixed to a bottom of the hull.

10. The craft of claim 7, further comprising:
a front hydrofoil assembly and a rear hydrofoil assembly that each extend from a lower surface of the hull and that facilitate hydrofoil borne operation of the craft, wherein at least one of the one or more third sensors is positioned along a front edge of a hydrofoil of the front hydrofoil assembly.

11. The craft of claim 1, further comprising:
one or more hydrofoil assemblies that extend from a lower surface of the hull and that facilitate hydrofoil-borne operation of the craft; and
one or more third sensors, wherein the instruction code causes the craft to:
receive third sensor data associated via the one or more third sensors;
determine, based at least in part on the third sensor data, whether the one or more hydrofoil assemblies are operating in a first state; and

when the one or more hydrofoil assemblies are determined to be operating in the first state, cause the craft to perform an operation to cause the one or more hydrofoil assemblies to operate in a second state.

12. The craft of claim 11, wherein the first state corresponds to the one or more hydrofoil assemblies not operating nominally and the second state corresponds to the one or more hydrofoil assemblies operating nominally.

13. The craft of claim 1, wherein a particular first sensor of the one of the one or more first sensors is configured to selectively extend and retract from an upper surface of the craft, and wherein the instruction code causes the craft to:

while the craft is airborne, maintain the particular first sensor in a retracted state;

determine that the craft has contacted water; and

after determining that the craft has contacted the water, cause the particular first sensor to extend from the craft.

14. The craft of claim 1, further comprising:

a plurality of propellers distributed across the wing, wherein a particular first sensor is a forward sensing propeller and is positioned behind a particular propeller of the plurality of propellers, and wherein the instruction code causes the craft to:

filter first sensor data associated with the particular first sensor so that propeller blades of the particular propeller are not sensed as above-water objects.

15. The craft of claim 1, wherein the predetermined path and the modified path correspond to paths that craft follows when the craft is airborne.

16. The craft of claim 1, wherein the predetermined path and the modified path correspond to paths that craft follows when the craft is hydrofoil-borne.

17. The craft of claim 1, when determining the modified path and causing the craft to travel according to the modified path comprises:

generating a conflict risk map that specifies potential collision zones between the craft and the one or more above-water objects;

generating a conflict avoidance path for avoiding potential conflict zones; and
communicating the generate a conflict risk map and the conflict avoidance path to a vehicle control system (VCS) is configured to operate one or more components of the craft to cause the craft to follow the conflict avoidance path.

18. The craft of claim 17, wherein the instruction code causes the craft to:
when the craft is airborne, cause the VCS to adjust one or more control surfaces of one or more of: flaps, ailerons, elevators, rudders, and vertical stabilizers of the craft to cause the craft to change its heading and altitude to follow the conflict avoidance path; and
when the craft is hydrofoil borne, cause the VCS to adjust one or more control surfaces of rudders of the craft or differentially control respective speeds of one or more of propeller assemblies of the craft to induce yaw into the craft to cause the cause the craft to to follow the conflict avoidance path.

19. The craft of claim 1, wherein the instruction code causes the craft to:
generate conflict risk map graphical representation that indicates one or more objects detected by one or more sensors of the craft along with corresponding track indications of the one or more objects; and
communicate the generated conflict risk map graphical representation to a user interface of the craft.

20. The craft of claim 1, wherein the instruction code causes the craft to:
time-synchronize sensor data generated by the one or more first sensors and the one or more second sensors;
normalize values specified in the time-synchronize sensor data, and
filter the normalized values to remove values that exceed one or more expected ranges.