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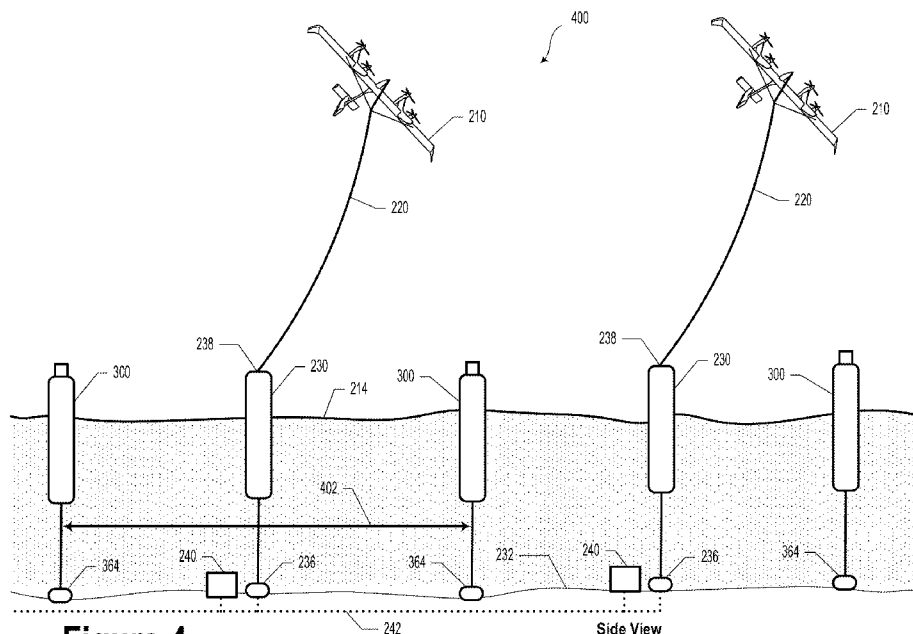


Figure 4

(57) Abstract: The present disclosure relates to systems and methods for operating aerial vehicles in water-based locations. Specifically, an exemplary system may include a floating tether station and an aerial vehicle coupled to the floating tether station by a tether. The system may also include a floating landing station. In such a scenario, the aerial vehicle may be configured to land on the landing station. In an example embodiment, the system may include a plurality of floating landing stations, where each floating landing station is coupled to the floating tether station. In such a scenario, at least three landing stations may be arranged about the tether station with a 120 degree azimuth spacing between adjacent landing stations.

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OFFSHORE WIND KITE WITH SEPARATE PERCH AND TETHER PLATFORMS**CROSS-REFERENCE TO RELATED APPLICATION**

[0001] This application claims the benefit of priority from U.S. Patent Application No. 15/387,476, filed December 21, 2016, which is hereby incorporated herein by reference in its entirety.

BACKGROUND

[0002] Unless otherwise indicated herein, the materials described in this section are not prior art to the claims in this application and are not admitted to be prior art by inclusion in this section.

[0003] Power generation systems may convert chemical and/or mechanical energy (e.g., kinetic energy) to electrical energy for various applications, such as utility systems. As one example, a wind energy system may convert kinetic wind energy to electrical energy.

SUMMARY

[0004] The present disclosure generally relates to systems and methods that incorporate aerial vehicles such as those employed in crosswind aerial vehicle systems. Crosswind aerial vehicle systems may extract useful power from the wind for various purposes such as, for example, generating electricity, lifting or towing objects or vehicles, etc. In some embodiments, the aerial vehicles may be operated above bodies of water, such as oceans, lakes, rivers, etc. Beneficially, embodiments described herein may provide expanded operating areas/regions for aerial vehicles.

[0005] In an aspect, a system is provided. The system includes a tether station and an aerial vehicle. The aerial vehicle is coupled to the tether station by a tether. The system also includes a landing station. The tether station and the landing station are configured to float on a body of water and the aerial vehicle is configured to land on the landing station.

[0006] In another aspect, a system is provided. The system includes a tether station, an aerial vehicle coupled to the tether station by a tether, and a landing station. At least one of the tether station or the landing station includes a fixed platform mounted on a seafloor. The aerial vehicle is configured to land on the landing station.

[0007] In a further aspect, a method is provided. The method includes determining a relative position between an aerial vehicle and a desired landing station. The aerial vehicle is coupled to a tether station by a tether. The tether station and the desired landing station are configured to float on a body of water. The tether station is coupled to the desired landing station by a coupling member. The coupling member is arranged above a surface of the body

of water or submerged. The method also includes causing the aerial vehicle to land on the desired landing station.

[0008] In a yet further aspect, a method is provided. The method includes receiving information about at least one of: a possible landing location for an aerial vehicle or a flight condition of the aerial vehicle. The aerial vehicle is coupled to a tether station by a tether. The tether station is configured to float on a body of water. The method also includes based on the received information, identifying a target landing location for the aerial vehicle. The method additionally includes causing the aerial vehicle to land at the target landing location.

[0009] Other aspects, embodiments, and implementations will become apparent to those of ordinary skill in the art by reading the following detailed description, with reference where appropriate to the accompanying drawings.

BRIEF DESCRIPTION OF THE FIGURES

[0010] Figure 1 illustrates a system, according to an example embodiment.

[0011] Figure 2 illustrates a system, according to an example embodiment.

[0012] Figure 3A illustrates a landing station, according to an example embodiment.

[0013] Figure 3B illustrates a landing station, according to an example embodiment.

[0014] Figure 3C illustrates a tether/landing station, according to an example embodiment.

[0015] Figure 4 illustrates a system, according to an example embodiment.

[0016] Figure 5 illustrates a system, according to an example embodiment.

[0017] Figure 6 illustrates a method, according to an example embodiment.

[0018] Figure 7 illustrates a method, according to an example embodiment.

DETAILED DESCRIPTION

[0019] Example methods, devices, and systems are described herein. It should be understood that the words “example” and “exemplary” are used herein to mean “serving as an example, instance, or illustration.” Any embodiment or feature described herein as being an “example” or “exemplary” is not necessarily to be construed as preferred or advantageous over other embodiments or features. Other embodiments can be utilized, and other changes can be made, without departing from the scope of the subject matter presented herein.

[0020] Thus, the example embodiments described herein are not meant to be limiting. 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, all of which are contemplated herein.

[0021] Further, unless 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.

I. Overview

[0022] Embodiments described herein relate to a system for over-water operation of a tethered aerial vehicle. Namely, an offshore energy kite system may include a tether station and a landing station, which may be located downwind of the tether station. The tether station and landing station may optionally be connected by a lateral coupling, which may be in or out of the water. The lateral coupling may be the length of the tether or shorter. The tether is not reeled so as to change a length of the tether between the tether station and the aerial vehicle. Rather, while the aerial vehicle is not in flight (e.g., stowed on the landing station), the tether may hang catenary between the two platforms, either in or out of the water or both. The tether station and/or the landing station may be anchored to the seafloor by a variety of means, including single anchor leg point, multi anchor leg mooring, etc. Additionally, the system may include an array of landing stations/tether points for offshore tethered energy kites may include a hexagonal close-packed arrangement of tether stations and landing stations in an (N+2) configuration.

[0023] In an example embodiment, the landing stations may be distributed such that, for N kites, there are N+2 landing stations. Each tether station is at the center of three landing stations, which are at 120 degree azimuth with respect to one another and around the tether station. In some embodiments, the landing stations may be arrayed away from the tether station at approximately a single tether length. The array of landing stations and tether stations may be anchored to the seafloor, or another fixed point, by one or more large drag anchors that may be arranged at various points in the array (e.g., around a perimeter of the array).

[0024] In an example embodiment, the landing stations can be disposed at a 120 degree azimuth from one another with respect to the tether station. Other angles are possible and contemplated. For example, four landing stations can be arranged about the tether station with 90 degree azimuth increments. In some embodiments, the landing stations may be disposed at approximately a single tether length from the tether station.

[0025] In an example embodiment, the aerial vehicle may be configured to fly at ± 60 degrees relative to the wind. As such, an array of landing stations arrayed at 120 degrees azimuth (with respect to the tether station) may provide a landing station that is always

“within reach” of the aerial vehicle regardless of prevailing wind direction. Embodiments may eliminate a fixed ground station altogether, leaving only an array of landing stations and tether stations. Furthermore, each landing station can have little or no machinery and need not require power, except for navigational lighting/beacons. In some example, the landing stations may generate electrical power from solar panels or a wind turbine.

II. Example Systems

[0026] Figure 1 illustrates a schematic diagram of system 100, according to an example embodiment. System 100 may include an aerial vehicle 110. The aerial vehicle 110 may include or take the form of various types of devices, such as a kite, a helicopter, a wing and/or an airplane, among other possibilities. The aerial vehicle 110 may be formed of structures including metal, plastic, and/or other polymers. The aerial vehicle 110 may be formed of any material which allows for a high thrust-to-weight ratio and generation of electrical energy which may be used in utility applications. Additionally, the materials may be chosen to allow for a lightning hardened, redundant, and/or fault tolerant design which may be capable of handling large and/or sudden shifts in wind speed and wind direction. Other materials may be possible as well.

[0027] The aerial vehicle 110 may be coupled to a first portion of a tether 120. In an example embodiment, the tether 120 may include two or more bridle segments, which may be coupled to various bridle attachment points on an airframe 112 of the aerial vehicle 110.

[0028] As an example, the tether 120 may include a core portion configured to withstand one or more forces of the aerial vehicle 110 when the aerial vehicle 110 is in hover flight, forward flight, and/or crosswind flight modes. The core portion of the tether may be constructed of any high strength fibers (e.g., carbon fiber, carbon nanotubes, polymer fibers, or another type of structural fiber). In some examples, the tether 120 may have a fixed length and/or a variable length. For instance, in at least one such example, the tether 120 may have a length of 140 meters. Other lengths of tether 120 are possible and contemplated.

[0029] In an example embodiment, the aerial vehicle 110 may include at least one hybrid electric motor configured to generate electricity while the aerial vehicle is operating in a cross-wind flight mode. That is, the aerial vehicle 110 may be operable to convert wind energy to electrical energy in an electrical energy generation operating mode.

[0030] The tether 120 may transmit electricity to the aerial vehicle 110 in order to power the aerial vehicle 110 for takeoff, landing, hover flight, and/or forward flight. The tether 120 may be constructed in any form and using any material which may allow for the transmission, delivery, and/or harnessing of electrical energy generated by the aerial vehicle

110 and/or transmission of electricity to the aerial vehicle 110. The tether 120 may also be configured to withstand one or more forces of the aerial vehicle 110 (e.g., tension and/or torsion loads) when the aerial vehicle 110 is in an operational mode.

[0031] The tether 120 may transmit electrical energy generated by the aerial vehicle 110. For example, the tether 120 may be configured to transmit electrical energy to an energy storage / power transmission element 140. That is, in an example embodiment, the tether 120 may provide electrical coupling between the aerial vehicle 110 and an electrical storage device. The energy storage / power transmission element 140 can include an electrical storage device such as a battery or a supercapacitor. Additionally or alternatively, the energy storage / power transmission element 140 can include an electrical conductor (a power line), a power grid, a generator, a pump, a power conversion device, or another type of electrical power element. In an example embodiment, the energy storage / power transmission element 140 can be located on the aerial vehicle 110, a tether station 130, or underwater (e.g., near the underwater mooring point for the tether station 130).

[0032] A second portion of the tether 120 may be coupled to the tether station 130. The tether station 130 may be configured to float on a body of water (e.g., a pond, lake, river, ocean, etc.). In such an embodiment, the tether 120 may remain out of the water while the aerial vehicle 110 is conducting flight operations. For example, the tether 120 may couple to an elevated portion of the tether station 130, such as a tower or another type of raised mount. In an example embodiment, the tether 120 may be coupled to the tether station 130 by a gimbal mount, a slip ring mount, a swivel, a rotational bearing, and/or another type of flexible or moveable coupling. While some embodiments herein are described as having a fixed length for tether 120, other embodiments may include a tether 120 having an adjustable working length. As an example, tether station 130 may include a tether reel configured to reel in, or pay out, the tether 120.

[0033] The tether station 130 may be configured to remain substantially stationary with respect to its position in the body of water. As an example, the tether station 130 may be coupled to an anchor or another type of fixed seafloor (or other form of lake bottom, river bottom, or ocean bottom) coupling by a variety of mooring systems. For example the tether station 130 may include a buoy portion coupled to the seafloor by a single anchor leg mooring (SALM) or a catenary anchor leg mooring (CALM). Other types of moorings are possible.

[0034] In an example embodiment, the tether station 130 may include another type of floating body. For example, the tether station 130 may include a barge or another type of boat.

[0035] Additionally or alternatively, the aerial vehicle 110 may be operable to convert wind energy into a mechanical tension in the tether 120. For example, the aerial vehicle 110 may include a mechanical “pump kite.” In such a scenario, the aerial vehicle 110 may be operable to fly along various flight paths, including figure-eight paths. Furthermore, the tether 120 may be coupled to a device (e.g., located on the tether station 130) operable to convert the mechanical energy in the tether 120 to electrical energy (e.g., to turn a shaft of an electrical generator).

[0036] The system 100 may include a controller 150. The controller 150 may include one or more processors 152 and a memory 154. The one or more processors 152 may be a general-purpose processor or a special-purpose processor (e.g., digital signal processors, application specific integrated circuits, etc.). The one or more processors 152 may be configured to execute computer-readable program instructions that are stored in the memory 154. As such, the one or more processors 152 may execute the program instructions to provide at least some of the functionality and operations described herein.

[0037] The memory 154 may include or take the form of one or more computer-readable storage media that may be read or accessed by the one or more processors 152. The one or more computer-readable storage media can include volatile and/or non-volatile storage components, such as optical, magnetic, organic or other memory or disc storage, which may be integrated in whole or in part with at least one of the one or more processors 152. In some embodiments, the memory 154 may be implemented using a single physical device (e.g., one optical, magnetic, organic or other memory or disc storage unit), while in other embodiments, the memory 154 can be implemented using two or more physical devices.

[0038] As noted, the memory 154 may include computer-readable program instructions and perhaps additional data, such as diagnostic data relating to aerial vehicle 110. As such, the memory 154 may include program instructions to perform or facilitate some or all of the functionality described herein.

[0039] The system 100 may include one or more landing stations 160. In an example embodiment, each landing station 160 of a plurality of landing stations may be coupled to at least one of: another landing station or an underwater mooring point. In an example embodiment, the landing station 160 may include a spar buoy, a floating landing platform, or another type of floating structure.

[0040] The landing station 160 may include a perch, a platform, or another suitable anchoring surface or member. The landing station 160 may be formed of any material that can suitably keep the aerial vehicle 110 attached and/or anchored to the landing station 160 while the aerial vehicle 100 is not conducting flight operations.

[0041] In an example embodiment, the aerial vehicle 110 may be configured to land on the landing station 160. That is, the landing station 160 may receive the aerial vehicle 110 during a landing operation. The landing station 160 may be used to hold and/or support the aerial vehicle 110 until it is in an operational flight mode. In an example embodiment, the landing station 160 may provide a safe landing location for the aerial vehicle 100 in the event of a storm or other conditions that are not suitable for flight operations. For example, if a wind speed (e.g., measured by a weather station on the landing station 160) exceeds a threshold wind speed (e.g., 160 kilometers per hour), the aerial vehicle 110 and/or controller 150 may select a landing station 160 from a plurality of landing stations. The aerial vehicle 100 may land at the selected landing station 160 to reduce the risk of damage to the aerial vehicle 110 or other parts of the system (e.g., the tether 120 and/or the tether station 130).

[0042] In some embodiments, after receiving an aerial vehicle 110, the landing station 160 may also be configured to allow for the repositioning of the aerial vehicle 110 such that redeployment of the device is possible. That is, aerial vehicle 110 may be configured to perform takeoff operations from and landing operations to the landing station 160. For instance, the landing station 160 may receive the aerial vehicle 110 for landing in a first orientation and adjust the aerial vehicle 110 to a second orientation for takeoff/launch operations.

[0043] In an example embodiment, a landing station 160 may be configured to receive a plurality of aerial vehicles concurrently using, for example, multiple perch locations. For instance, a given landing station 160 may be configured to provide concurrent landing facilities (e.g., perches) for two, three, or more aerial vehicles 110.

[0044] Two or more elements of system 100 may be communicatively coupled using a communication interface. The communication interface may include one or more wireless interfaces and/or one or more wired interfaces. As an example, such a communication interface may provide a communication link between the landing station 160 and the aerial vehicle 110 using one or more networks. As described herein, wireless interfaces may provide for communication under one or more wireless communication protocols, such as Bluetooth, Wi-Fi (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. Wired interfaces may include an Ethernet interface, a Universal Serial Bus (USB) interface, or similar interface to communicate using 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. In an example embodiment, the landing station 160 may communicate with the aerial vehicle 110, other landing stations, and/or other entities (e.g., a command center) using the communication system.

[0045] In an example embodiment, the controller 150 may be configured to determine a relative position between an aerial vehicle 110 and a landing station 160 while the aerial vehicle 110 is conducting flight operations. As an example, the controller 150 may determine the relative position based on position data received from aerial vehicle 110 (e.g., from a GPS unit) and/or the landing station 160.

[0046] Based on the determined relative position, the controller 150 may be configured to cause the aerial vehicle 110 to land on the landing station 160. As an example, the aerial vehicle 110 may couple to a perch or another type of structure on the landing station 160.

[0047] In an example embodiment, the tether station 130 may be coupled to the landing station 160 by a coupling member (e.g., a lateral catenary coupling). The coupling member may be arranged above a surface of the body of water and/or submerged. In such a scenario, causing the aerial vehicle 110 to land on the landing station 160 may include adjusting a length of the coupling member and a corresponding distance between the landing station 160 and the tether station 130. That is, the length of the coupling member between the landing station 160 and the tether station 130 can be reeled in, or payed out, so as to bring the landing station 160 and/or the tether station 130 into proper position so as to land the aerial vehicle 110. Alternatively, tether station 130 and landing station 160 can be uncoupled.

[0048] Figure 2 illustrates a side view of system 200, according to an example embodiment. System 200 may include at least some of the elements of system 100 as illustrated and described in relation to Figure 1. For example, system 200 includes an aerial vehicle 210, which may include one or more hybrid drives 212 that may be operable to generate electrical energy and/or thrust for the aerial vehicle 210.

[0049] The aerial vehicle 210 may be configured to fly substantially along a path 214 to generate electrical energy. The path 214 may include a substantially circular shape or another curved shape. For example, path 214 may include an oval-shaped flight pattern oriented substantially perpendicular to a prevailing wind direction 216, however other orientations are possible. The term “substantially along,” as used in this disclosure, refers to

exactly along and/or one or more deviations from exactly along that do not significantly impact generation of electrical energy as described herein.

[0050] The path 214 may include a variety of shapes in different embodiments. For example, the path 214 may be substantially circular. And in at least one such example, the path 214 may have a radius of up to 265 meters. The term “substantially circular,” as used in this disclosure, refers to exactly circular and/or one or more deviations from exactly circular that do not significantly impact generation of electrical energy as described herein. Other shapes for the path 214 may be an oval, such as an ellipse, the shape of the numeral 8 (“a figure-eight”), etc.

[0051] As described herein, the aerial vehicle 210 may be coupled to a tether station 230 by a tether 220. In an example embodiment, the tether station 230 may include a coupling point 238. The coupling point 238 may include a moveable coupling, such as a swivel mount, a gimbal mount, a split-ring mount, etc. As such, coupling point 238 may provide a moveable and/or flexible coupling between the tether 220 and the tether station 230. The tether station 230 may be configured to float on a water surface 214. The tether station 230 may be anchored or otherwise moored to an underwater mooring point 236, which may be located on a seafloor 232 (e.g., ocean bottom, lake bottom, etc.).

[0052] In some embodiments, the tether 220 may provide an electrical connection to the aerial vehicle 210. Furthermore, the tether 220 may be electrically coupled, by the tether station 230, to an energy storage device 240 and/or an electrical transmission system 242 (e.g., a power grid, a power distribution system, etc.).

[0053] While not illustrated herein, it is contemplated that a length of tether 220 may be adjusted by a tether reel or another type of winding mechanism. The tether reel, which may be located between the tether station 230 and the aerial vehicle 210, can provide an adjustable and/or controllable working length for the tether 220. In other embodiments, tether 220 may have a fixed length.

[0054] In some embodiments, the aerial vehicle 210 can include landing gear or another type of structure suitable for stabilizing and/or anchoring the aerial vehicle 210 to a surface or structure during non-flight operations. For example, the landing gear may include a gripper mechanism configured to couple to a perch structure. In another example embodiment, the landing gear may include tires, legs, and/or skids. Yet further, the landing gear may be configured to engage with at least a portion (e.g., a landing perch 368) of the landing station 300 described below.

[0055] Figures 3A and 3B illustrate side views of several embodiments of landing stations, which may include various floating structures configured to receive aerial vehicles. As illustrated, each landing station may be configured to receive one aerial vehicle during non-flight operations. However, it is understood that landing stations may have a landing capacity of greater than one aerial vehicle. For instance, a landing station may be configured to receive two, three, or more aerial vehicles.

[0056] Figure 3A illustrates a landing station 300, according to an example embodiment. The landing station 300 may be similar or identical to landing station 160 as illustrated and described in relation to Figure 1. The landing station 300 may include a floating structure 360, which may include a spar buoy; however other types of floating structures are contemplated. Some non-limiting examples of floating structures 360 may include a boat, a barge, or a catamaran structure. The floating structure 360 may include a landing perch 368. The landing perch 368 may include a fixed arm, a moveable arm, a net, a peg, or another type of structure configured to receive an aerial vehicle (e.g., aerial vehicle 210) during landing operations.

[0057] The landing station 300 may include a single anchor leg mooring (SALM) 362. As an example, the SALM 362 may couple the floating structure 360 to an anchor 364 or another type of fixed coupling proximate to the seafloor 232. Additionally or alternatively, the floating structure 360 may be moored by a catenary anchor leg mooring (CALM) or a multi anchor leg mooring (MALM). Other mooring arrangements are contemplated for the landing station 300. For example, the floating structure 360 may be coupled to one or more other floating structures by a lateral coupling (e.g., a lateral tether or catenary), which may be disposed above, at, and/or below water level. As an example, adjacent “nearest neighbor” landing stations can be coupled to one another by lateral couplings so as to maintain a substantially stationary position within an array of landing stations.

[0058] In an example embodiment, the landing station 300 may be coupled to a tether station (e.g., tether station 230) by a coupling member. For example, the coupling member may be arranged above a surface of the body of water or submerged.

[0059] Figure 3B illustrates a landing station 370, according to an example embodiment. Landing station 370 includes a floating structure 360 that may be coupled to a platform 372. Landing station 370 may additionally include one or more solar panels 374 and/or one or more wind turbines 376. As such, the landing station 370 may be configured to generate at least some electrical power.

[0060] Figure 3C illustrates a tether/landing station 380, according to an example embodiment. In an example embodiment, landing station 380 may be configured to function as both a tether point for an aerial vehicle (e.g., a tether station) as well as a landing station for the tethered aerial vehicle or another aerial vehicle.

[0061] As an example, tether/landing station 380 may include a tether tower 382. A tether 220 of an aerial vehicle 210 may be coupled to the landing station 380 by the tether tower 382. Furthermore, the platform 372 may accommodate the aerial vehicle 210 or another aerial vehicle (e.g., tethered to an adjacent tether station) during non-flight operations (e.g., upon landing).

[0062] Figure 4 illustrates a side view of a system 400, according to an example embodiment. System 400 may include elements from systems 100, 200, 300, 370, and 380 as illustrated and described in relation to Figures 1, 2, 3A, 3B, and 3C. Namely, system 400 may include a plurality of aerial vehicles 210, which may be attached to respective tethers 220 and their respective tether stations 230.

[0063] System 400 also includes a plurality of landing stations 300 that are arranged about respective tether stations 230. For example, at least three landing stations 300 may be arranged about each respective tether station 230 with a 120 degree azimuth spacing between adjacent landing stations 300. The landing stations 300 may be moored to respective mooring locations 364. A distance 402 between the landing station mooring locations 364 may be based on a length of the tether 220. That is, the distance 402 may be slightly less than the length of tether 220 such that aerial vehicle 210 can land at adjacent landing stations 300.

[0064] In an example embodiment, the plurality of landing stations 300 may be arranged in substantially a hexagonal-close packed (HCP) arrangement. Other geometrical arrangements square array, linear array, octagonal arrays, etc. are possible.

[0065] Figure 5 illustrates an overhead view of system 500, according to an example embodiment. System 500 may include elements that are similar or identical to corresponding elements of systems 100, 200, 300, 370, 380, and 400 as illustrated and described in relation to Figures 1, 2, 3A, 3B, 3C, and 4. System 500 includes an arrangement of a plurality of tether stations 230 and a plurality of landing stations 300. In an example embodiment, system 500 may include a plurality of aerial vehicles (e.g., 210a-c) that are attached to the respective tether stations 230a-c by respective tethers 220a-220c.

[0066] A prevailing wind direction 502a-c may be measured, for example, by the aerial vehicle 210a-c, by one or more tether stations 230a-c, or by one or more landing

stations 300. Additionally or alternatively, the prevailing wind direction 502a-c can be received from other sources of weather information.

[0067] Based on the prevailing wind direction 502a-c, the respective aerial vehicles 210a-c may be configured to fly within an operation envelope 506a-c, which may include a 120 degree angular sector centered about the wind direction 502a-c. In other words, in an example embodiment, the aerial vehicles 210a-c may be operable to conduct tethered flight operations within an angular region ± 60 degrees from the wind direction 502a-c.

[0068] In an example embodiment, for a system 500 that includes N aerial vehicles 210, the number of landing stations 300 may be at least N+2. For example, in the example illustrated in Figure 5, for three aerial vehicles 210a-c, system 500 may include at least five landing stations 300 (e.g., seven landing stations total, with a “shared” landing station 300a). It is understood that many different numbers and arrangements of both aerial vehicles 210 and landing stations 300 are contemplated in the present disclosure.

[0069] For example, a plurality of landing stations 300 can be arranged in a landing station array. In such a scenario, each tether station may be located within a group of three possible landing stations in the landing station array. Furthermore, one or two landing stations of the group may be “shared” with another aerial vehicle. That is, in some scenarios, neighboring aerial vehicles can land on the same landing station, based on, for example, prevailing wind conditions and/or the landing capacity of the landing station.

[0070] Furthermore, while the plurality of landing stations 300 can be arranged with a periodic shape (e.g., a hexagonal close-packed lattice or square lattice), other arrangements are possible. For instance, the plurality of landing stations can be arranged about the respective tether mooring points at a given distance based on a length of the tether 220.

[0071] In some embodiments, some or all of the landing stations can be coupled by lateral coupling members, which may include lateral tethers 520, 522, and 524. The lateral tethers 520, 522, and 524 may be catenary members located above, at, and/or under the water surface. Additionally, as described herein, the landing station 300 can include a buoy or a floating landing platform.

[0072] In other examples, landing stations 300 can represent other types of target landing locations. For example, some target landing locations need not correspond to a physical structure for receiving an aerial vehicle. In such scenarios, the target landing location may include a water location and the aerial vehicle may be controlled to land on the water at the target landing location.

[0073] While Figure 5 illustrates a particular number of aerial vehicles, it is understood that more or fewer aerial vehicles are possible and their tethering arrangement and locations can include many different combinations. For example, a plurality of aerial vehicles can be tethered to the same tether station. Furthermore, a plurality of aerial vehicles can be arranged along a given tether. As such, an arrangement of landing stations within the landing station array may vary based on such considerations.

[0074] While various embodiments described herein include floating stations (e.g., buoys), one or both of the tether station or the landing station can include a fixed platform mounted on a seafloor. That is, tether stations and/or landing stations described herein can be rigidly fixed to a seafloor, riverbed, lakebed, or another solid bottom of a body of water. For example, the fixed platform can include concrete and/or steel legs that may be directly anchored into or onto the seabed. In such scenarios, apart from the fixed nature of their platforms, tether stations and landing stations can be similar or identical to their floating counterparts.

III. Example Methods

[0075] Figure 6 illustrates a method 600, according to an example embodiment. The method 600 may include various blocks or steps. The blocks or steps may be carried out individually or in combination. The blocks or steps may be carried out in any order and/or in series or in parallel. Further, blocks or steps may be omitted or added to method 600.

[0076] The blocks of method 600 may control, include, and/or involve elements of systems 100, 200, 300, 370, 380, 400, and 500 as illustrated and described in reference to Figures 1, 2, 3A, 3B, 3C, 4, and 5. In some embodiments, some or all blocks of method 600 may be carried out by controller 150.

[0077] Block 610 may include determining a relative position between an aerial vehicle and a desired landing station. In such a scenario, the aerial vehicle may be coupled to a tether station by a tether. Furthermore, the tether station and the desired landing station may be configured to float on a body of water. The tether station is coupled to the desired landing station by a coupling member. The coupling member is arranged above a surface of the body of water or submerged. That is, the tether station and the landing station may be connected by the coupling member, which can be a catenary tether configured to maintain a spacing between the tether station and the landing station.

[0078] Block 620 may include causing the aerial vehicle to land on the desired landing station. In an example embodiment, causing the aerial vehicle to land on the landing station can include adjusting a length of the coupling member and a corresponding distance

between the desired landing station and the tether station. That is, the coupling member can be reeled in or payed out so as to change the distance between the landing station and the tether station. As an example, the length of the coupling member can be adjusted such that the distance between the landing station and the tether station is substantially similar to the length of the tether.

[0079] In some embodiments, the desired landing station may include a landing perch. In such a scenario, causing the aerial vehicle to land on the desired landing station may include causing the aerial vehicle to couple to the landing perch.

[0080] As described elsewhere herein, the aerial vehicle may be configured to generate electrical power using at least one hybrid electric motor while operating in a cross-wind flight mode.

[0081] Optionally, the method 600 may include selecting a desired landing station from a plurality of landing stations. In such a scenario, each landing station of the plurality of landing stations may be coupled to the tether station (e.g., by respective lateral coupling members). At least three landing stations can be arranged about the tether stations with a 120 degree azimuth spacing between adjacent landing stations. Furthermore, at least one of the landing stations may be anchored to the seafloor by a single anchor leg mooring or a multi anchor leg mooring.

[0082] Selecting the desired landing station can include, for example, receiving information indicative of a wind speed and a wind direction. Wind direction data can include information indicative of an average wind direction (e.g., in degrees). For example, the wind direction data can be received from a weather sensor on a landing station or on an aerial vehicle. The wind direction data can be obtained from other weather information sources.

[0083] In such a scenario, selecting the desired landing station can be based on the wind speed and/or the wind direction. For example, for a prevailing wind out of the north, the selected landing station can include a landing station located within a 120 degree operating envelope centered along a southerly direction.

[0084] Other information can be used to determine the desired landing station. For example, the desired landing station can be determined based on a position data and/or a relative distance between the aerial vehicle and a given landing station. Position data can include information indicative of a position of the aerial vehicle and/or information indicative of a position of one or more landing stations. The position data may be provided from, for example, a global positioning system (GPS) receiver located on an aerial vehicle or a landing station.

[0085] Position data can take other forms and may be obtained in other ways. For example, position data may include information indicative of a relative distance between a given aerial vehicle and a possible landing station. In such a scenario, the position data can include a received signal strength of a navigational radio beacon. As such, the position data may include information indicative of an absolute position of a landing station or a relative position of the landing station with respect to the aerial vehicle. In other words, the selection of the landing station can be based on the closest possible landing station. Additionally or alternatively, the selection of the landing station can be based on the landing station that is the closest in heading to the prevailing wind direction. Yet further, the selection of the landing station can be performed based on a shortest anticipated amount of time to complete landing operations.

[0086] Alternatively or additionally, desired landing stations may be determined based on, for instance, the number of landing perches on the respective landing station, a battery state of charge on the aerial vehicle, and/or other factors. In some cases, the selection of the landing station may be performed based on at least two criteria. For example, the selection of the landing station can be based primarily on the wind direction and secondarily on a landing capacity of the respective landing station. Other criteria are possible and contemplated herein.

[0087] Figure 7 illustrates a method 700, according to an example embodiment. Method 700 may include various blocks or steps. The blocks or steps may be carried out individually or in combination. The blocks or steps may be carried out in any order and/or in series or in parallel. Further, blocks or steps may be omitted or added to method 700.

[0088] The blocks of method 700 may control, include, and/or involve elements of systems 100, 200, 300, 370, 380, 400, and 500 as illustrated and described in reference to Figures 1, 2, 3A, 3B, 3C, 4, and 5. In some embodiments, some or all blocks of method 700 may be carried out by controller 150.

[0089] Block 702 includes receiving information about at least one of: a possible landing location for an aerial vehicle or a flight condition of the aerial vehicle. The aerial vehicle is coupled to a tether station by a tether. The tether station is configured to float on a body of water.

[0090] The information about the possible landing location may include, without limitation, at least one of: a position data of the possible landing location, a wind speed at the possible landing location, a wind direction at the possible landing location, or a water

condition at the possible landing location. Other types of information about the possible landing location are possible and contemplated herein.

[0091] The information about the flight condition of the aerial vehicle may include, without limitation, at least one of: position data of the aerial vehicle, an airspeed of the aerial vehicle, a wind speed at the aerial vehicle, a groundspeed of the aerial vehicle, a heading of the aerial vehicle, a severe weather indication, or a maintenance indication. Other types of information about the flight condition of the aerial vehicle are possible and contemplated herein.

[0092] A severe weather indication may be received based on a forecasted weather condition (e.g., wind speed, maximum gust speed, lightning strike probability, etc.) that may be outside the normal operating envelope of the aerial vehicle.

[0093] A maintenance indication may be received based on a general or specific maintenance issue with the aerial vehicle. For instance, a maintenance indication may be received in response to a low oil level, a low hydraulic fluid level, a low battery level, or another type of mechanical, electrical or aerodynamic abnormality or emergency.

[0094] Block 704 includes based on the received information, identifying a target landing location for the aerial vehicle. Block 704 may include identifying, and selecting from, a plurality of possible landing locations. For example, the received information in Block 702 may include information about a plurality of possible landing locations. In such a scenario, identifying the target landing location may include selecting the target landing location from the plurality of possible landing locations. The target landing location may be identified and/or selected based on, for example, a relative position of the aerial vehicle and a given possible landing location. Alternatively, the target landing location may be identified or selected based on an emergency need. For example, in the case that the aerial vehicle experiences a maintenance or mechanical emergency, method 700 may select a water surface for landing.

[0095] Block 706 includes causing the aerial vehicle to land at the target landing location. In an example embodiment, causing the aerial vehicle to land at the target landing location can include causing the aerial vehicle to carry out landing operations so as to land at a landing station or a water surface location.

[0096] In some embodiments, the possible landing location(s) may include at least one of: a landing station or a water surface. The landing stations may be configured to float on a body of water and may be similar or identical to landing station 160 as illustrated and described with regard to Figure 1.

[0097] The particular arrangements shown in the Figures should not be viewed as limiting. It should be understood that other embodiments may include more or less of each element shown in a given Figure. Further, some of the illustrated elements may be combined or omitted. Yet further, an illustrative embodiment may include elements that are not illustrated in the Figures.

[0098] A step or block that represents a processing of information can correspond to circuitry that can be configured to perform the specific logical functions of a herein-described method or technique. Alternatively or additionally, a step or block that represents a processing of information can correspond to a module, a segment, or a portion of program code (including related data). The program code can include one or more instructions executable by a processor for implementing specific logical functions or actions in the method or technique. The program code and/or related data can be stored on any type of computer readable medium such as a storage device including a disk, hard drive, or other storage medium.

[0099] The computer readable medium can also include non-transitory computer readable media such as computer-readable media that store data for short periods of time like register memory, processor cache, and random access memory (RAM). The computer readable media can also include non-transitory computer readable media that store program code and/or data for longer periods of time. Thus, the computer readable media may include secondary or persistent long term storage, like read only memory (ROM), optical or magnetic disks, compact-disc read only memory (CD-ROM), for example. The computer readable media can also be any other volatile or non-volatile storage systems. A computer readable medium can be considered a computer readable storage medium, for example, or a tangible storage device.

[00100] While various examples and embodiments have been disclosed, other examples and embodiments will be apparent to those skilled in the art. The various disclosed examples and embodiments are for purposes of illustration and are not intended to be limiting, with the true scope being indicated by the following claims.

CLAIMS

What is claimed is:

1. A system comprising:
 - a tether station;
 - an aerial vehicle coupled to the tether station by a tether; and
 - a landing station, wherein the tether station and the landing station are configured to float on a body of water, wherein the aerial vehicle is configured to land on the landing station.
2. The system of claim 1, wherein the tether station is coupled to the landing station by a coupling member, wherein the coupling member is arranged above a surface of the body of water or submerged.
3. The system of claim 1, wherein at least one of the tether station or the landing station are anchored to a seafloor by a single anchor leg mooring or a multi anchor leg mooring.
4. The system of claim 1, wherein at least one of the tether station or the landing station comprises a buoy or a floating platform.
5. The system of claim 1, further comprising a controller configured to carry out operations, the operations comprising:
 - determining a relative position between the aerial vehicle and the landing station; and
 - causing the aerial vehicle to land on the landing station.
6. The system of claim 5, wherein the tether station is coupled to the landing station by a coupling member, wherein the coupling member is arranged above a surface of the body of water or submerged, wherein causing the aerial vehicle to land on the landing station comprises adjusting a length of the coupling member and a corresponding distance between the landing station and the tether station.
7. The system of claim 1, further comprising:
 - a plurality of landing stations, wherein each landing station of the plurality of landing stations is coupled to the tether station, wherein at least three landing stations are

arranged about the tether station with a 120 degree azimuth spacing between adjacent landing stations.

8. The system of claim 7, wherein each landing station of the plurality of landing stations comprises a landing perch, wherein the aerial vehicle is configured to couple to the landing perch.

9. The system of claim 7, further comprising N aerial vehicles, wherein the plurality of landing stations comprises N+2 landing stations.

10. The system of claim 7, further comprising a plurality of aerial vehicles coupled to respective tether stations by respective tethers, wherein the plurality of landing stations comprises a hexagonal close-packed arrangement, wherein the respective tether stations are located at the center of each group of three nearest neighbor landing stations in the hexagonal close-packed arrangement, wherein the plurality of landing stations are arranged about the respective tether station at a given distance based on a length of the respective tether.

11. The system of claim 1, wherein the aerial vehicle comprises at least one hybrid electric motor configured to generate electrical power while the aerial vehicle is operating in a cross-wind flight mode, wherein the aerial vehicle is electrically coupled to an electrical storage device by the tether.

12. The system of claim 1, further comprising at least one anchor, wherein at least one of: the tether station or the landing station is coupled to the at least one anchor.

13. A system comprising:

a tether station;

an aerial vehicle coupled to the tether station by a tether; and

a landing station, wherein at least one of the tether station or the landing station comprises a fixed platform mounted on a seafloor, wherein the aerial vehicle is configured to land on the landing station.

14. The system of claim 13, further comprising a controller configured to carry out operations, the operations comprising:

determining a relative position between the aerial vehicle and the landing station; and causing the aerial vehicle to land on the landing station.

15. A method comprising:

determining a relative position between an aerial vehicle and a desired landing station, wherein the aerial vehicle is coupled to a tether station by a tether, wherein the tether station and the desired landing station are configured to float on a body of water, wherein the tether station is coupled to the desired landing station by a coupling member, wherein the coupling member is arranged above a surface of the body of water or submerged; and causing the aerial vehicle to land on the desired landing station.

16. The method of claim 15, wherein causing the aerial vehicle to land on the landing station comprises adjusting a length of the coupling member and a corresponding distance between the desired landing station and the tether station.

17. The method of claim 15, wherein the desired landing station comprises a landing perch, wherein causing the aerial vehicle to land on the desired landing station comprises causing the aerial vehicle to couple to the landing perch.

18. The method of claim 15, further comprising, while the aerial vehicle is operating in a cross-wind flight mode, generating electrical power with at least one hybrid electric motor.

19. The method of claim 15, further comprising selecting a desired landing station from a plurality of landing stations, wherein each landing station of the plurality of landing stations is coupled to the tether station, wherein at least three landing stations are arranged about the tether stations with a 120 degree azimuth spacing between adjacent landing stations, wherein at least one of the landing stations is anchored to the seafloor by a single anchor leg mooring or a multi anchor leg mooring.

20. The method of claim 19, wherein selecting the desired landing station comprises receiving information indicative of a wind speed and a wind direction, wherein selecting the desired landing station is based on the wind speed and the wind direction.

21. A method comprising:

receiving information about at least one of: a possible landing location for an aerial vehicle or a flight condition of the aerial vehicle, wherein the aerial vehicle is coupled to a tether station by a tether, wherein the tether station is configured to float on a body of water;

based on the received information, identifying a target landing location for the aerial vehicle; and

causing the aerial vehicle to land at the target landing location.

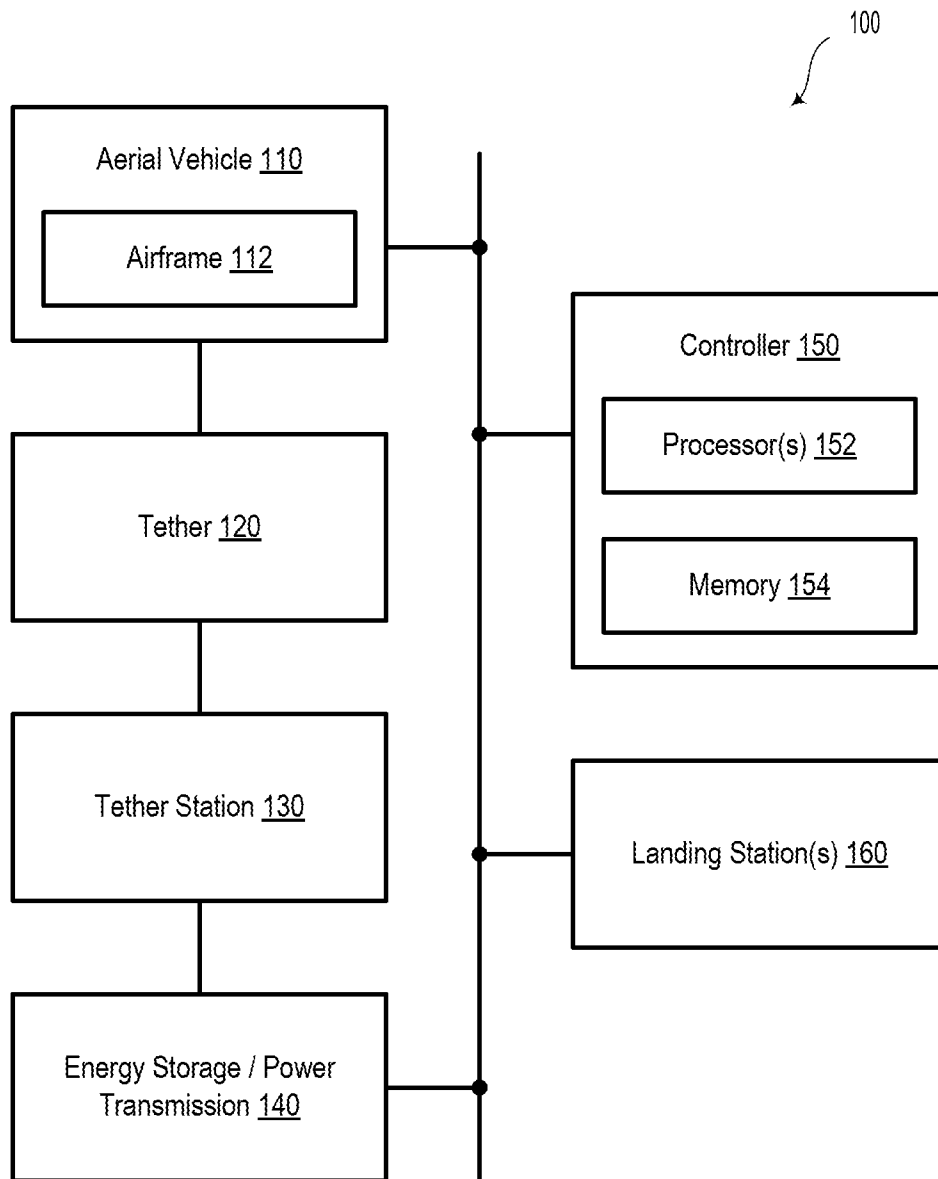
22. The method of claim 21, wherein the information about the possible landing location comprises at least one of: a position data of the possible landing location, a wind speed at the possible landing location, a wind direction at the possible landing location, or a water condition at the possible landing location.

23. The method of claim 21, wherein the information about the flight condition of the aerial vehicle comprises at least one of: position data of the aerial vehicle, an airspeed of the aerial vehicle, a wind speed at the aerial vehicle, a groundspeed of the aerial vehicle, a heading of the aerial vehicle, a severe weather indication, or a maintenance indication.

24. The method of claim 21, wherein the received information comprises information about a plurality of possible landing locations and wherein identifying the target landing location comprises selecting the target landing location from the plurality of possible landing locations.

25. The method of claim 21, wherein the possible landing location comprises at least one of: a landing station or a water surface, wherein the landing station is configured to float on a body of water.

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**Figure 1**

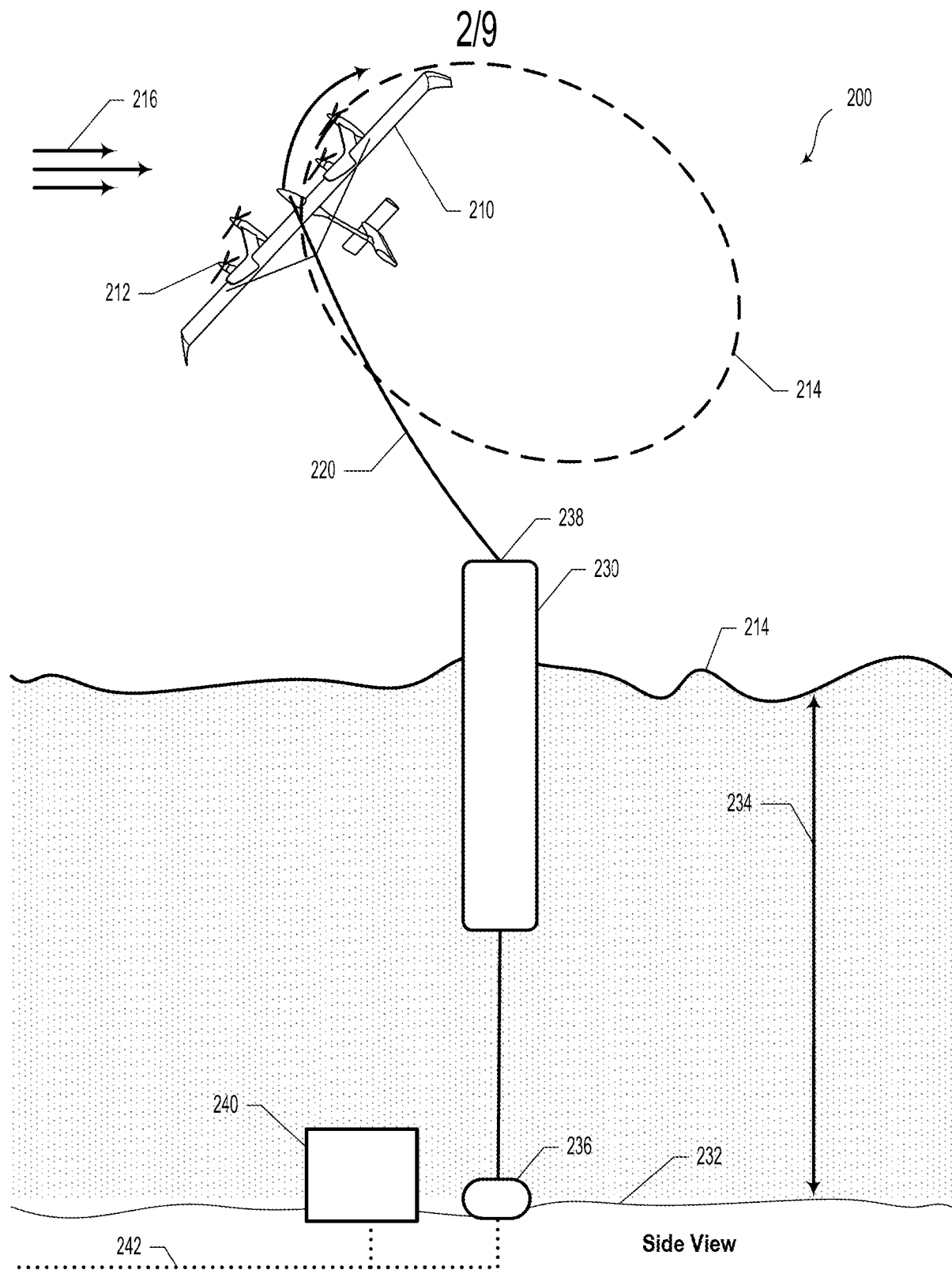
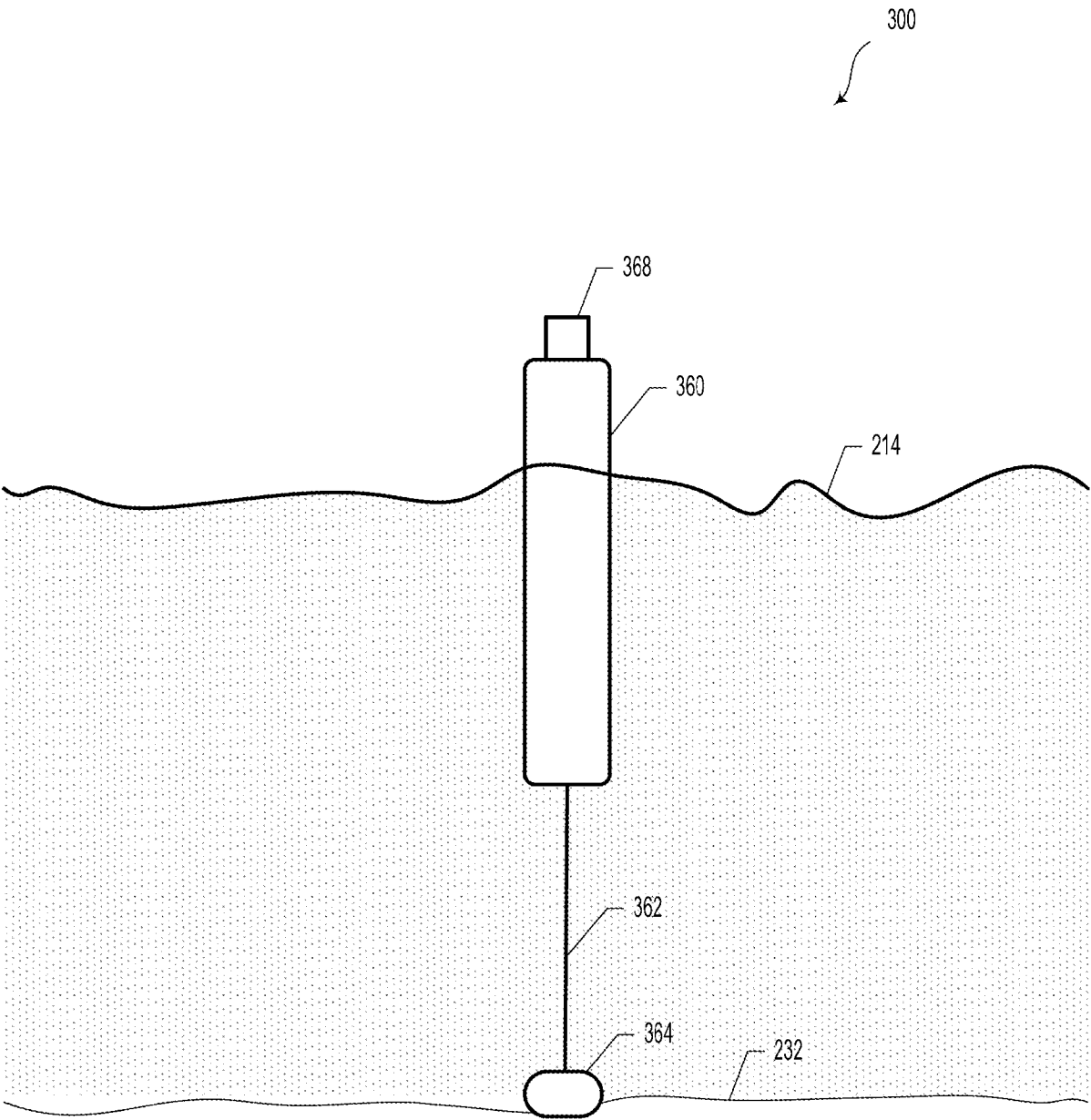


Figure 2

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Side View

Figure 3A

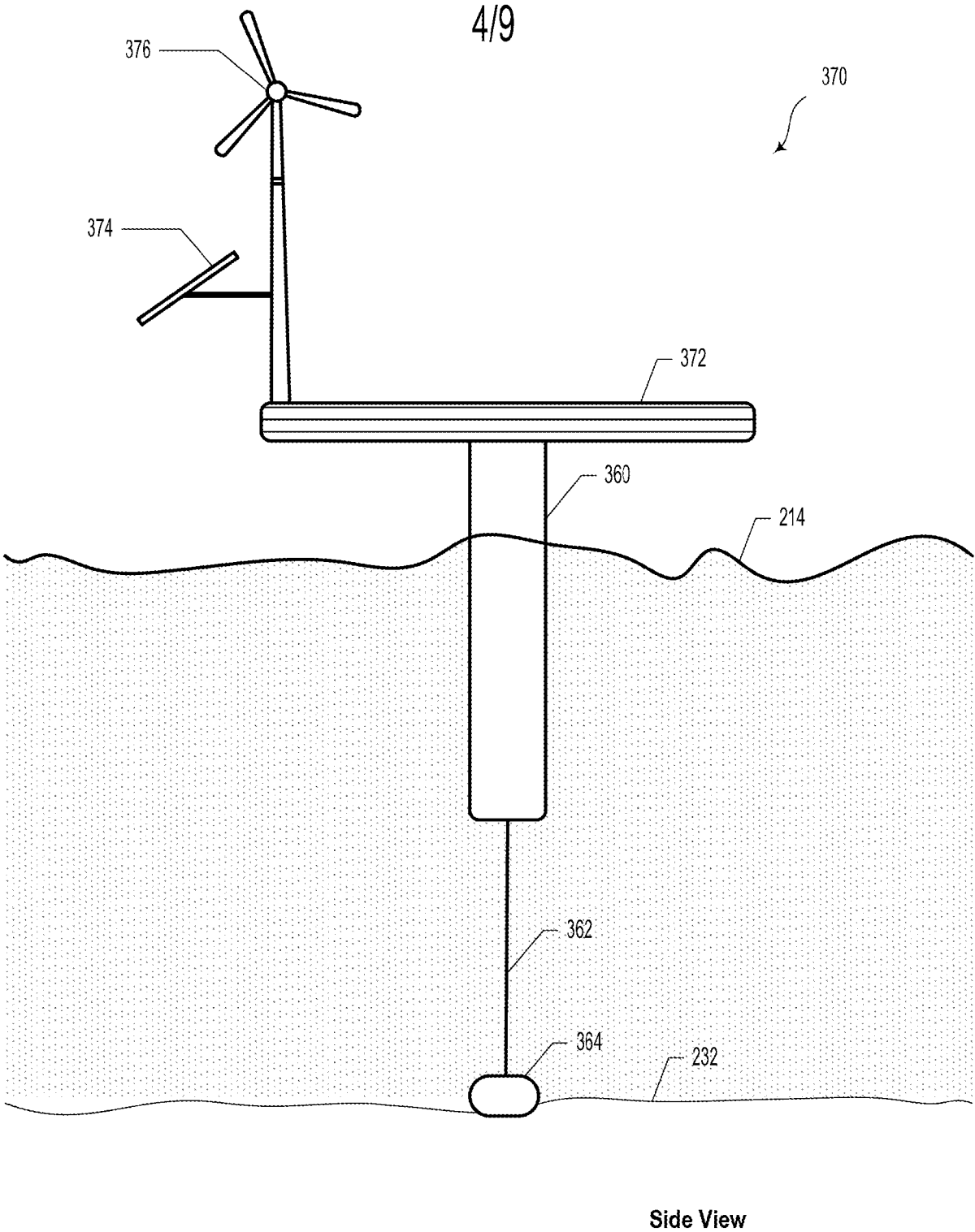
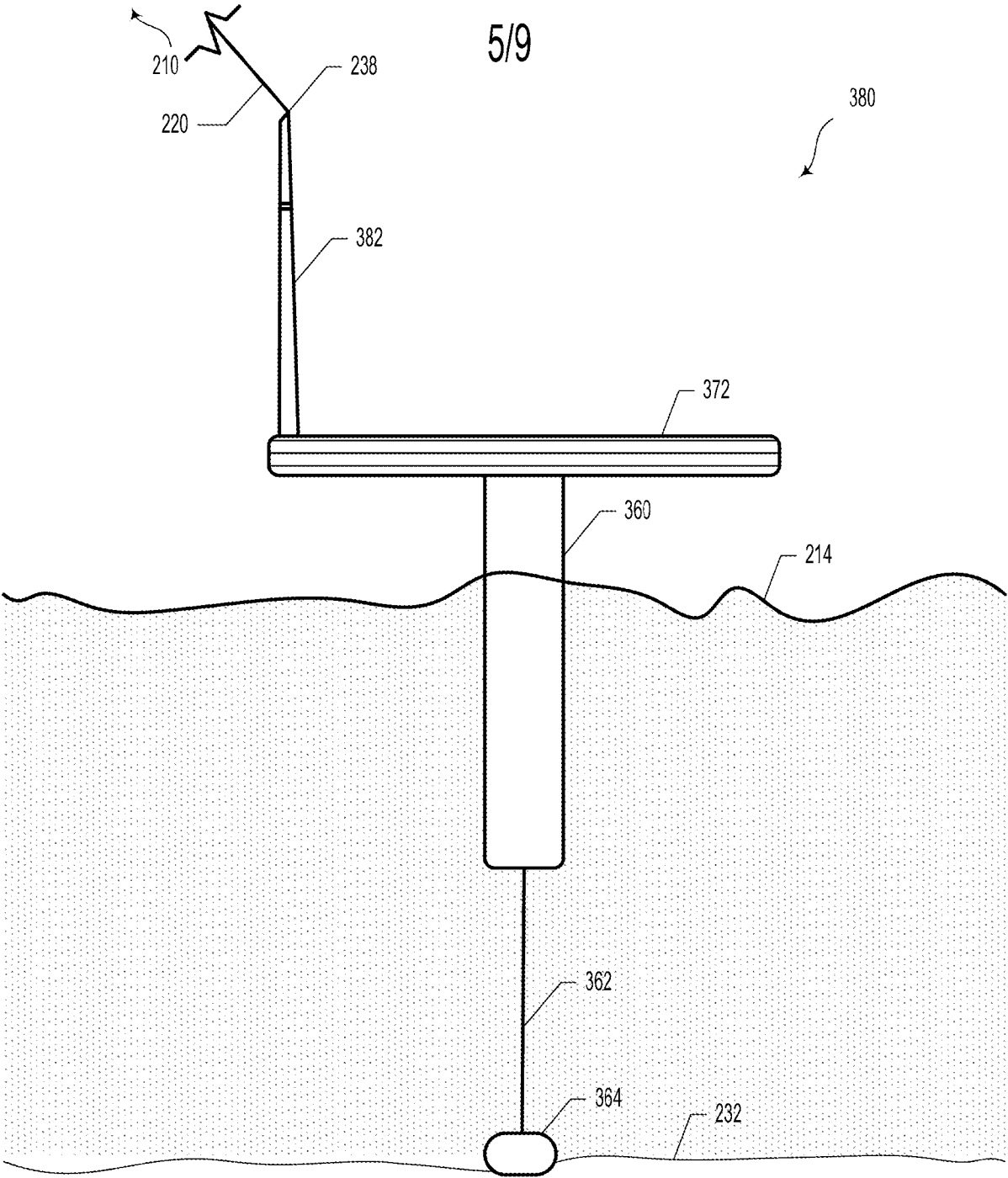


Figure 3B



Side View

Figure 3C

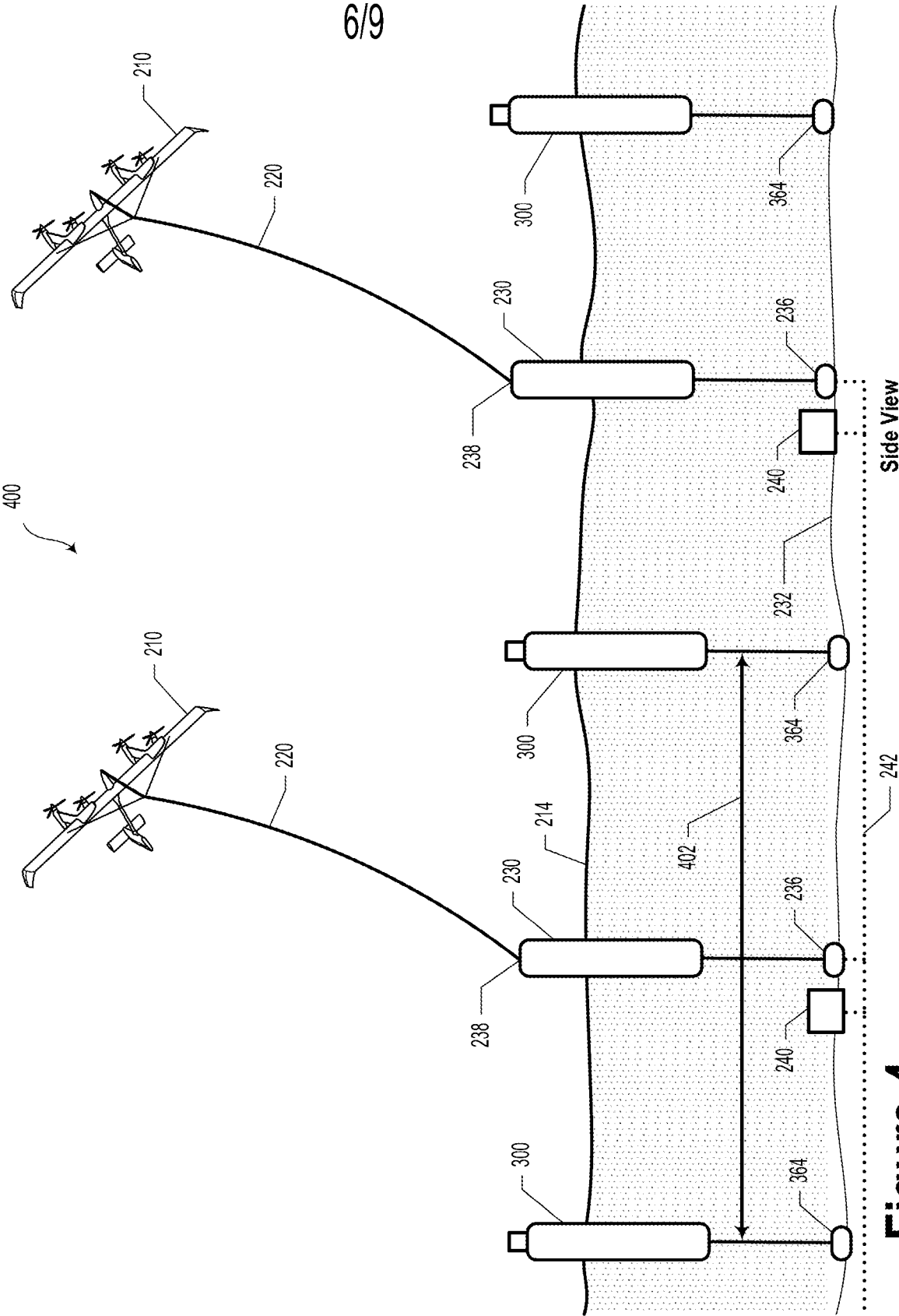


Figure 4

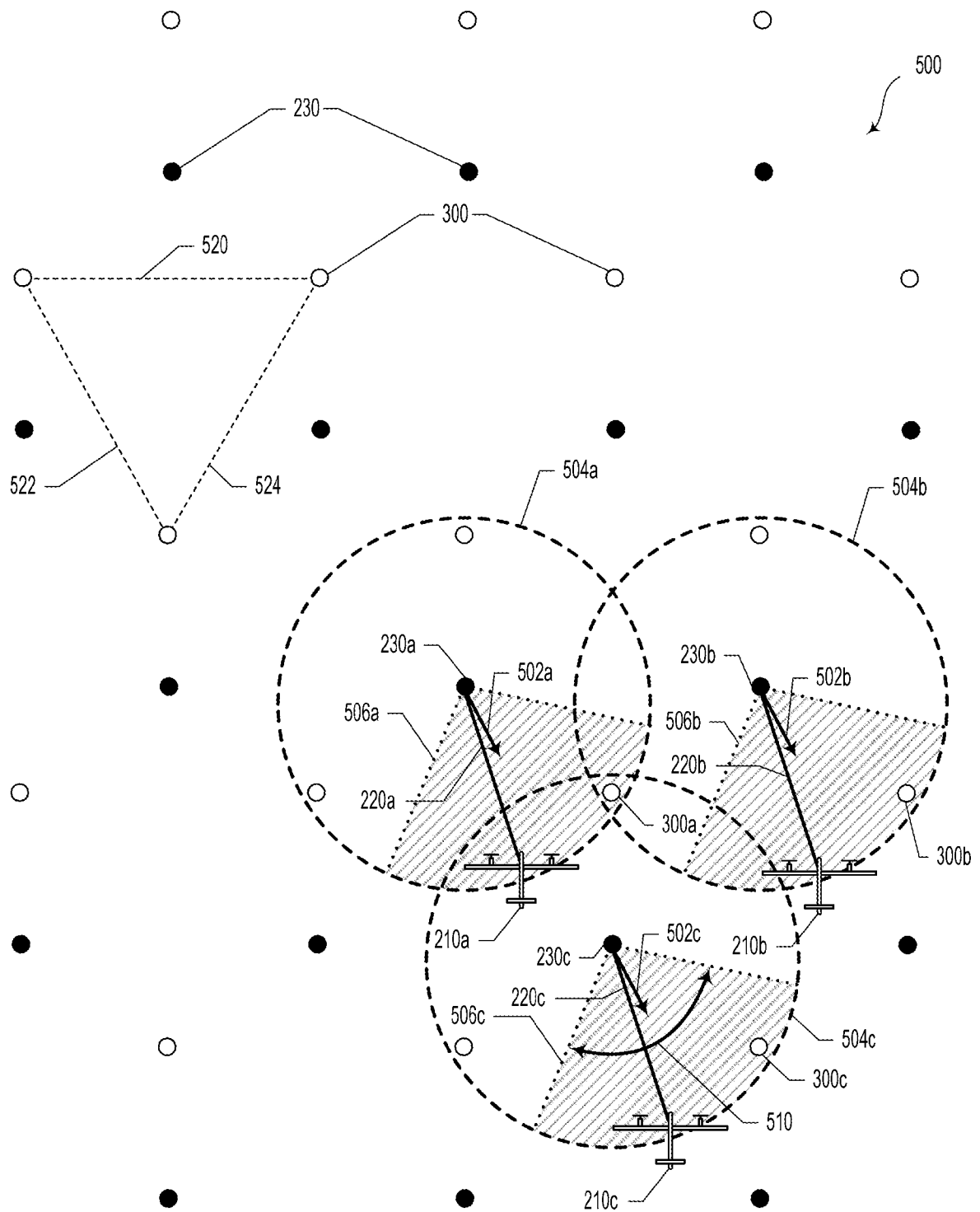


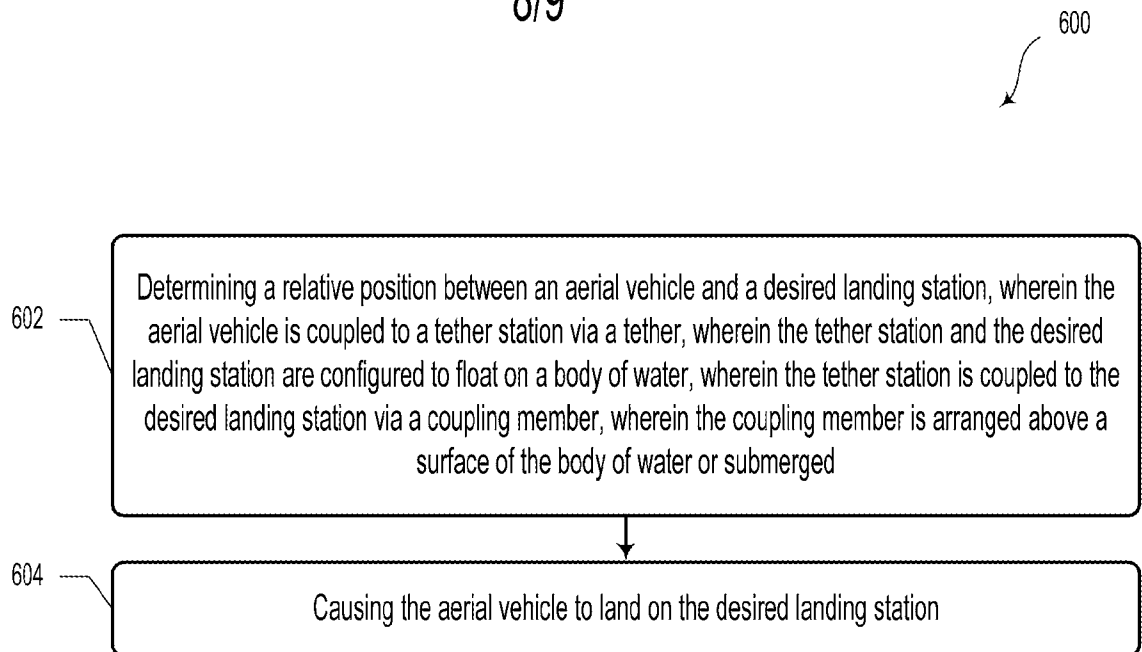
Figure 5

Top View

Tether Station ●

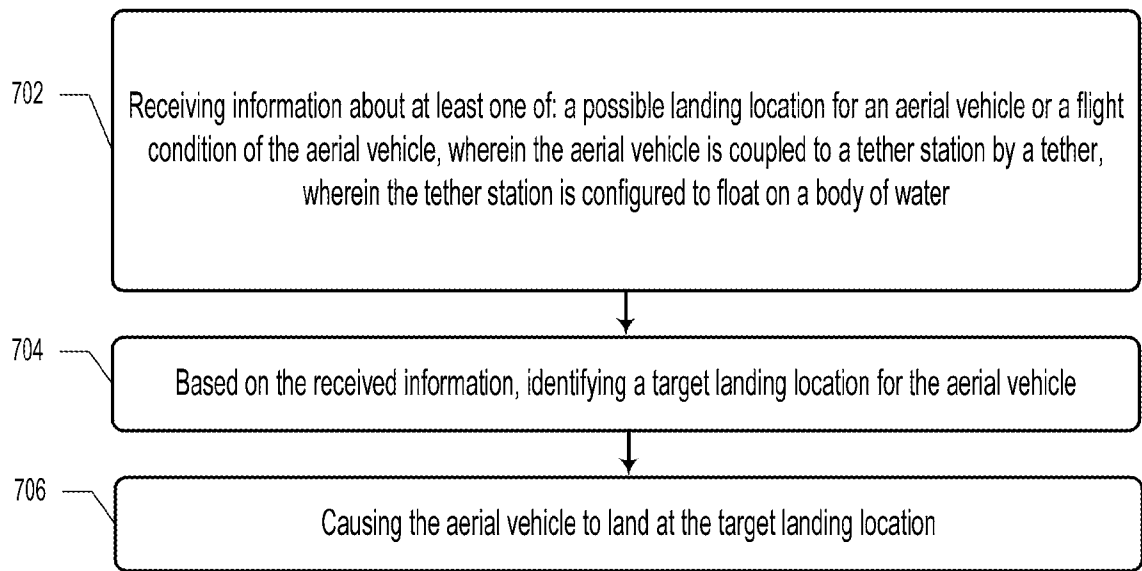
Landing Station ○

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**Figure 6**

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700

**Figure 7**

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2017/057175**A. CLASSIFICATION OF SUBJECT MATTER****F03D 5/00(2006.01)i, B64C 39/02(2006.01)i, B63B 35/53(2006.01)i, B66D 1/60(2006.01)i**

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F03D 5/00; F03D 7/00; B64B 1/24; B64F 1/36; B64C 39/02; B64F 3/02; G05D 1/00; B64F 1/12; F03D 9/00; B63B 35/53; B66D 1/60

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & Keywords: electrical, aerial vehicle, platform, landing and tether

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2010-0032948 A1 (BEVIRT, JOEBEN) 11 February 2010 See paragraphs [0031]-[0073] and figures 1(a)-3(g), 11.	1, 2, 4-6, 11, 13-16, 18
Y		3, 7-10, 12, 17, 19-25
Y	US 2016-0318628 A1 (GOOGLE INC.) 03 November 2016 See paragraph [0054] and figures 3-4.	3, 8, 12, 17, 19, 20
Y	US 9139310 B1 (SZ DJI TECHNOLOGY CO., LTD.) 22 September 2015 See column 6, line 4-column 8, line 62.	7-10, 19-25
A	US 2016-0236776 A1 (GOOGLE INC.) 18 August 2016 See paragraphs [0027]-[0038], [0077] and figures 1-2, 7.	1-25
A	US 2015-0097086 A1 (EWIND SOLUTIONS, LLC) 09 April 2015 See paragraphs [0024]-[0055] and figures 1-3.	1-25



Further documents are listed in the continuation of Box C.



See patent family annex.

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

14 February 2018 (14.02.2018)

Date of mailing of the international search report

22 February 2018 (22.02.2018)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea



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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2017/057175

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