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(54) Title: WING-TYPE SAIL SYSTEM

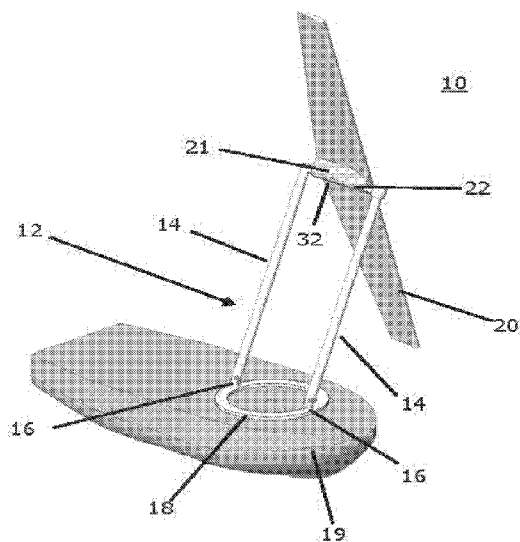


FIG. 3

(57) Abstract: A wing-type sail system is provided. The system includes a mast assembly pivotally mounted on a swiveling base attachable to a craft and a substantially rigid multi-element asymmetric wing pivotally attached to a top of the mast assembly. The system further includes a control mechanism for modifying roll and yaw of the substantially rigid wing with respect to the craft.



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WING-TYPE SAIL SYSTEM

FIELD AND BACKGROUND OF THE INVENTION

5 The present invention relates to a wing-type sail system and, more particularly, to a rigid wing mid-mounted on a mast assembly configured for controlling the roll and yaw and optionally pitch and height of the wing with respect to a vessel.

 Wing-type sails are known for use on both land and sea-type wind-powered vehicles. By comparison with traditional soft sails, wing-type sails are typically rigid or
10 semi-rigid symmetrical airfoils that develop lift from the passage of wind thereupon; a wing-type sail is typically mounted vertically and is pivotable about its vertical axis.

 Generating useful propulsive force in any given direction requires the ability to controllably align the angle of attack of the wing relative to the direction of the wind.

 Since mast-mounted wing-type sails need to convert a 'lift' force to a forward
15 moving force under starboard and port wind directions, the profile of the wing has to be symmetric (around the profile centerline) - a less than optimal profile for maximizing lift forces.

 Thus, it would be highly advantageous to have a wing-type sail system devoid of the above limitations.

20 SUMMARY OF THE INVENTION

 According to one aspect of the present invention there is provided a wing-type sail system comprising: (a) a mast assembly pivotally mounted on a swiveling base attachable to a craft; (b) a substantially rigid wing pivotally attached to a top of the mast assembly, the wing having an asymmetric profile (airfoil); and (c) a control mechanism
25 for modifying a roll and yaw of the substantially rigid wing with respect to the craft.

 According to further features in preferred embodiments of the invention described below, the wing is pivotally attached to a top of the mast assembly at a central portion thereof.

 According to still further features in the described preferred embodiments the
30 mast assembly forms a triangular tower.

 According to still further features in the described preferred embodiments the wing is oriented to wind side by rolling the wing and rotating the swiveling base.

According to still further features in the described preferred embodiments a top of the triangular tower is attached to the wing through a pin-type hinge.

According to still further features in the described preferred embodiments the mast assembly includes a plurality of mast poles each being separately connected to the
5 swiveling base and the wing.

According to still further features in the described preferred embodiments the control mechanism includes control wires for modifying the roll and yaw of the wing.

According to still further features in the described preferred embodiments the control mechanism is further capable of modifying a height or pitch of the wing.

10 According to still further features in the described preferred embodiments a length of each of the plurality of mast poles is telescopically adjustable.

According to still further features in the described preferred embodiments the wing is pivotally attached to the mast assembly around a center of gravity of the wing.

According to still further features in the described preferred embodiments the
15 system further comprising wind speed and direction sensors mounted on the mast assembly and/or on the wing.

According to still further features in the described preferred embodiments the system further comprising a level angle sensor mounted on the swiveling base.

According to still further features in the described preferred embodiments the
20 system further comprising a control unit for actuating the control mechanism according to information selected from the group consisting of wind speed, wind direction, vessel longitudinal direction, a level angle of the swiveling base, and an angle of the roll and yaw of the substantially rigid wing.

According to still further features in the described preferred embodiments the
25 wing is foldable.

According to still further features in the described preferred embodiments the wing is telescopically foldable.

According to still further features in the described preferred embodiments the control unit is wired to the control mechanism.

30 According to still further features in the described preferred embodiments the control unit wirelessly communicates with the control mechanism.

According to still further features in the described preferred embodiments the wing includes a leading edge and/or a trailing edge extension.

According to still further features in the described preferred embodiments the extension is shaped as a winglet having an asymmetric airfoil shape.

5 According to still further features in the described preferred embodiments the winglet has an asymmetric profile.

According to another aspect of the present invention there is provided a vessel comprising a plurality of the systems described herein.

10 According to still further features in the described preferred embodiments the vessel is a cargo ship, a tanker, a cruise liner or a yacht.

According to still further features in the described preferred embodiments the vessel further comprises a control unit for controlling each control mechanism of the plurality of systems.

15 The present invention successfully addresses the shortcomings of the presently known configurations by providing a wing-type sail system which enables a user to control the roll and yaw of a substantially rigid asymmetric profile wing having a very high lift coefficient (C_{Lmax} higher than 3.0, up to about 4.5 or more) with respect to the vessel, thus enabling a user to optimize the angle of the wing with respect to the wind.

20 Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Although methods and materials similar or equivalent to those described herein can be used in the practice or testing of the present invention, suitable methods and materials are described below. In case of conflict, the patent specification, including definitions, will control. In addition, the materials, methods, and examples are
25 illustrative only and not intended to be limiting.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

The invention is herein described, by way of example only, with reference to the accompanying drawings. With specific reference now to the drawings in detail, it is
30 stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention only, and are presented in the cause of providing what is believed to be the most useful and readily understood

description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

In the drawings:

FIG. 1 illustrates various airfoil shapes (wing profiles).

FIGs. 2a-e illustrate starboard to port tacking of a prior art symmetric wing-type sail.

FIG. 3 illustrates one embodiment of the present wing-type sail system.

FIGs. 4a-e illustrate starboard to port tacking of the wing-type sail of Figure 3.

FIG. 5 illustrates another embodiment of the wing-type sail system of the present invention.

FIG. 6 illustrates the swiveling base and mast assembly of the wing-type sail system of Figure 5.

FIGs. 7a-b illustrate a vessel fitted with a plurality of the wing-type sail systems of Figures 3 and 5.

FIG. 8 is a flow chart diagram illustrating a closed control loop control utilizable by the present system; Abbreviations: Vaz - Vessel azimuth; Waz - Apparent wind azimuth; Bangle - swiveling base angle relative to vessel longitudinal centerline. Bangle = 0 when Swiveling base centerline align with vessel centerline. Bangle < 0 when swiveling base centerline points to starboard and Bangle > 0 when swiveling base centerline points to port side; $160 > \text{Bangle} > -160$; Wangle - wing angle in vertical plane relative to base level; wangle=0 when wing is horizontal; wangle < 0 when wing is angled left side (when looking from trailing edge to leading edge) and Wangle > 0 when wing is angled right side; $90 > \text{Wangle} > -90$.

FIG. 9 is an image of a model boat fitted with a prototype system constructed in accordance with the teachings of the present invention.

FIGs. 10a-e illustrate a prototype multi-hull vessel (Figures 10a-b, d) fitted with a wing-type sail (Figures 10c-d) constructed in accordance with the teachings of the present invention. Figure 10e illustrates the airfoil of the prototype wing.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is of a wing-type sail system which can be used as a propulsion or a propulsion-assist device on land or water vehicles.

The principles and operation of the present invention may be better understood
5 with reference to the drawings and accompanying descriptions.

Before explaining at least one embodiment of the invention in detail, it is to be understood that the invention is not limited in its application to the details of construction and the arrangement of the components set forth in the following description or illustrated in the drawings. The invention is capable of other
10 embodiments or of being practiced or carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein is for the purpose of description and should not be regarded as limiting.

Rigid wing-type sails similar in structure and function to an aircraft wing are known in the prior art. Such sails provide sail-like functionality via a rigid, lift
15 optimized structure which produces a forward 'lift' when mounted upright on a vessel, i.e. it produces a force in the forward direction on the vessel thereby propelling the vessel forward.

Although rigid wing-type sails are efficient at harnessing the wind, they suffer from several inherent limitations.

20 Since wing-type sails are typically mounted upright on a vertical mast the profile of such wings must be symmetric around the profile centerline (Figure 1 at B, centerline shown by dashed line) in order to enable generation of forward 'lift' under all tacking directions (starboard and port sail orientations). Figures 2a-e illustrates tacking under changing wind/movement directions in a vessel with a symmetric wing-type sail
25 mounted on an upright mast (W - wind direction, D - vessel sailing direction).

Although symmetric wing sails (Figure 1 at B) can generate at least as much lift as an ordinary sail (Figure 1 at A) they generate less lift than an asymmetric airfoil wing sail (Figure 1 at D and E). In order to solve this limitation of symmetric wing sails, sail manufacturers have added a trailing edge winglet (See Figure 1 at C) which increases the
30 maximum lift coefficient of the symmetric wing. Such a configuration is substantially more efficient in harnessing the wind than an ordinary sail and has been utilized by boats racing the America's Cup.

Configurations utilizing mid-mounted pivoting wing-type sails are also known. One example of such a sail system is the Aeroskimmer (www.dcss.org/speedweek/aeroskimmer.html). Although the Aeroskimmer solves most of the aforementioned problems, control over the wing and in particular, adjusting wing alignment to changing wind directions is difficult to achieve due to its mast system and its connection to the wing.

An asymmetric wing (asymmetric around the profile center line) generates more lift than a symmetric wing since it maximizes the difference in the speed of air flowing over the top side (convex/cambered) and the bottom side (flat or concave). This in turn maximizes the static pressure difference between the top and bottom surfaces of the wing and the lift force pointing from the concave side to the cambered side (per Bernoulli's law).

While reducing the present invention to practice, the present inventor has devised a wing-type sail system that traverses the aforementioned limitations of prior art systems to provide:

(i) an asymmetric wing sail having a maximum lift coefficient much higher than that of presently used wing sails for maximizing propulsion of small as well as large boats and ships;

(ii) a mast assembly that enables control over wing roll and yaw in order to enable correct positioning of the wing sail profile with respect to the wind to generate forward 'lift';

(iii) a mast assembly that is robust enough to support and move the wing sail to achieve optimized orientation with respect to the wind; and

(iv) an optional folding mechanism that enables folding and stowage of both wing and mast assembly.

Thus, according to one aspect of the present invention there is provided a wing-type sail system. As used herein, a wing-type sail refers to a substantially rigid sail that has wing functionality, i.e. it can generate lift from air flowing over its surface. As used herein, the phrase "substantially rigid" refers to a wing structure that has a rigid cover, i.e. a cover that maintains its shape and is not dependent on wind for shaping.

The wing-type sail of the present invention can include a wing-like frame (spars and profiles) covered with a stretched fabric, a polymer or a composite (fiberglass,

carbon fiber). Alternatively, the wing-type sail of the present invention can be a solid structure composed of a lightweight foam core that is covered with a composite.

The present system includes a mast assembly pivotally mounted on a swiveling base attachable to a water craft/vessel (e.g. yacht, racing boat, ship and the like) or a land craft/vehicle (e.g. land yacht). The swiveling base can be attached to the deck or to a structure mounted on the deck or hull. The present system further includes a substantially rigid wing pivotally attached to a top of the mast assembly, preferably at the mid wing point (e.g. center of gravity) such that it balances on top of the mast assembly.

The wing sail of the present invention has an asymmetric airfoil (profile) in order to maximize lift. An asymmetric profile is exemplified by D and E in Figure 1.

Table 1 below lists the maximum lift coefficients of various wing profiles. An asymmetric airfoil has a maximum lift coefficient that can be 30-40% higher than that of an ordinary sail (Figure 1 at A) and a symmetric profile wing (Figure 1 at B). An asymmetric airfoil with a leading slat and trailing winglet can generate a maximum lift coefficient of 4.5, three times the lift per m^2 of surface of an ordinary sail.

Table 1

Figure 1	Wing shape	CLmax
A	Flat Cambered profile (sail)	1.5 – 1.3
B	Symmetric profile	1.5
C	Symmetric profile with trailing edge winglet	2.5-2.8
D-E	Asymmetric profile	1.5 – 2.0
F	Asymmetric profile with trailing edge winglet	3.1
G	Asymmetric profile with leading slat and a trailing edge winglet	4.5

The wing sail of the present invention can also include leading and/or trailing edge elements shaped as asymmetric (or symmetric) slats or winglets (Figure 1 at F and G) in order to further increase lift. As is shown in table 1 above, addition of such elements can increase the maximum lift coefficient by a factor of 2 - 3.

Various configurations of the wing sail of the present invention are described in greater detail hereinbelow.

In order to enable an asymmetric wing to generate lift from winds of all tacking directions, i.e., to allow tacking in all directions while still maintaining forward lift, the

wing sail of the present invention is mounted on a mast assembly that both rotates and flips the wing sail when tacked (i.e. controls both roll and yaw of the wing).

The mast assembly can include one or more masts (e.g. 1, 2, 4, 8 masts) that are attached to a swiveling base (turret) which is attached to the vessel. The top of the masts are attached to a mid portion (around or at the center of gravity) of the wing sail via a hinge assembly which can include an axle/shaft/rod/pin fitted within friction/roller bearings. The hinge assembly enables the wing sail to roll around the hinge axis from an upright position (vertical or nearly vertical) on one side of the mast assembly to an upright position on an opposite side of the mast assembly (see description related to Figures 4a-e below for further detail). The swiveling base can rotate the wing assembly such that the leading edge of the wing sail is correctly angled with respect to the wind to provide lift.

The mast assembly can alternatively include telescoping masts that can be selectively actuated to roll the wing sail by lifting one side and lowering the other.

Various configurations of the mast assembly of the present invention are described hereinbelow in greater detail.

The present system also includes a control mechanism for modifying a height, pitch, roll and yaw of the wing with respect to the craft as well as a wing span thereof. The control mechanism can include winch motors, hydraulic pumps, mechanical or electric transmission, or the like for angling the mast assembly and for raising or lowering each of the masts. The control mechanism preferably includes winch motors and pulleys which are attached via rigging (e.g. steel, Kevlar wires) to the top of the mast assembly and to the wing tips.

The control mechanism can be integrated or attached to the swiveling base or it can be positioned below deck with wires running through the deck to the mast assembly.

The present system further includes a control unit for enabling an operator (e.g. ship captain) to control actuation of the mast assembly and angle of the wing attached thereto via the control mechanism.

Referring now to the drawings, Figures 3-4e illustrate one configuration of the wing-type sail system of the present invention which is referred to herein as system 10.

System 10 includes a mast assembly 12 which in this embodiment includes 2 masts 14 attached via hinges or ball joints 16 to a base 18. Base 18 can be circular (as

shown in Figure 3) or any other suitable shape (square, rectangular, star, cross, and the like). Base 18 can be fabricated from galvanized plate steel or any other alloy (aluminum alloy), while masts 14 can be fabricated from aluminum, carbon fiber or a combination thereof. Base 18 can be mounted to a vessel 19 on a circular track/rail with rollers and a motor for rotating base 18 within the track.

Masts 14 can be telescopic to extend or retract to adjust a height and pitch of an attached wing 20. Masts 14 can include a spring mechanism (coil spring or an air piston) which is compressible when masts 14 are pulled down and retracted. When a pulling force is partially or fully released, the compressed spring mechanism extends masts 14.

An asymmetric rigid wing 20 is attached on top of mast assembly 12 through a hinge 22. Hinge 22 includes a pin running through center section 21 of wing 20 between masts 14. The pin can rotate within center section 21 or it can be fixed thereto and rotate against bearings in masts 14. Hinge 22 allows wing 20 to roll from one side (Figure 4a) of mast assembly 12 to the opposite side (Figure 4e). A control mechanism 32 which includes motors and cables/chains/belts can be positioned within center section 21 and/or within masts 14 to control roll of wing 20. Alternatively, an external rigging of cables attached to wing 20 (at tips or inward) and to pulleys and motors (similar to that described for system 100) can also provide the roll function.

Control mechanism 32 also controls rotation (swivel) of base 18 with respect to the vessel by controlling one or more motors within base 18.

The skeleton (spars and profiles) of wing 20 is fabricated from an alloy, a polymer, carbon fiber or wood and is covered with rigid or semi-rigid panels (alloy, polymer, carbon fiber or cloth). Wing 20 can be constructed from several foldable or telescopic segments (which can be retracted/expanded via control mechanism) similar to wing 120 shown in Figure 5.

Wing 20 can be fabricated with a variety of dimensions depending on the craft and purpose. Typical dimensions for wing 20 can be selected from a range of 5 m in length, 1 m in width for small catamarans, trimarans or sailing boats, up to 50 m in length and 20 m in width for large super or mega yachts (single hull, catamarans or trimarans), or small, medium, large ships. Wing 20 can be a single foil (as shown in the Figures) or a multi-foil configuration (2, 3 or 4 sections) with the main wing attached to

leading edge and/or trailing edge winglets (e.g. slats, flaperons or ailerons). As is described hereinabove, multi-foil configurations generate a high lift coefficient ($C_{Lmax} > 3$) and are preferred in all sea wind velocities. Wing 20 having a multi-foil configuration and $C_{Lmax} = 4.5$ can provide about 280 Newton force per m^2 surface area at a typical
5 wind speed of 10 m/s and 10^0 air temperature.

Figures 4a-e illustrate repositioning (tacking) of system 10 in order to change sailing direction (D) under a steady wind (wind direction - D). Figures 4a-e illustrate a change of 70^0 in route direction in 14^0 increments. The vessel is turned 70^0 clockwise causing the wind direction to rotate 70^0 anti clockwise from front right to front left. In
10 order to adjust the position of wing 20 according to the wind direction, wing 20 is rolled clockwise from -80^0 to $+80^0$ while base 18 is rotated 34^0 counterclockwise [from $+35^0 - 18^0$ (angle of attack) to $-35^0 + 18^0$ (angle of attack)] relative to the vessel's longitudinal centerline.

Such roll and yaw of wing 20 as affected through hinge 22 and mast assembly 12
15 can be used to reposition wing 20 to maximize lift under any change in wind direction or vessel route.

The wing repositioning approach used by the present invention, which separates the roll and yaw function to two different mechanisms, allows for a stable and robust attachment between wing 20 and mast assembly 12, thus making the present invention
20 suitable for use under any wind condition and with any size vessel and wing.

Figures 5-7b illustrates another configuration of the wing-type sail system of the present invention which is referred to herein as system 100.

System 100 includes a mast assembly 102 which in this embodiment includes 4 masts 104 attached via hinges or ball joints 106 to a base 108. Base 108 can be circular
25 (as shown in Figures 5-6) or any other suitable shape (square, rectangular, star, cross, and the like). Base 108 can be fabricated from galvanized plate steel or any other alloy (aluminum alloy), while masts 104 can be fabricated from aluminum, carbon fiber or a combination thereof.

Masts 104 are preferably telescopic and include 2 or more segments (three
30 shown) that can telescopically extend or retract to adjust a height, pitch yaw or roll of an attached wing 120. Masts 104 can include a spring mechanism (coil spring or an air piston) which is compressible when masts 104 are pulled down and retracted. When a

pulling force is partially or fully released, the compressed spring mechanism extends masts 104.

A substantially rigid asymmetric wing 120 is attached on top of mast assembly 102 through hinged/ball joints 22; wing 120 is preferably separately connected to each mast 104 through a dedicated hinge/ball joint 122.

The skeleton (spars and profiles) of wing 120 can be fabricated as described above for wing 20. Wing 120 can be constructed from several foldable or telescopic segments 124 (which can be retracted / expanded via control mechanism). In the embodiment shown in Figure 5, wing 120 includes 7 interconnected segments 124; with segments 126 and 128 being telescopically retractable into segment 130 (using mechanical or hydraulic mechanisms).

Wing 120 can be fabricated with a variety of dimensions depending on the craft and purpose and can be a single foil (as is shown in the Figures) or a multi-foil configuration.

System 100 also includes a control mechanism 132 which includes motors 134 with attached pulleys 136 (shown in detail in Figure 6). Braided steel or aramid cables (guy wires) 138 (four shown) are spooled over pulleys 136. Thus, motors 134 and attached pulleys 136 function as winches for pulling or releasing cables 138. Each pulley 136 functions independently to spool a cable 138 attached thereto. As is shown in Figures 5-6, a pair 140 of cables 138 is preferably connected to each pulley 136 (cables 138 can be a single cable looped over pulley 136). Each cable 136 of the pair is connected to a different portion of wing 120. For example, one cable 136 is connected to end of wing 120, while the other is connected to a midsection of wing 120 at or near joint 122. Such a cabling configuration is important for ensuring that lift forces on wing 120 do not deflect it from its set position and that lift forces transferred to the swiveling base and to the vessel by the wires are distributed.

Cables 138 enable control mechanism 132 to tilt wing 120 through pitch, roll and yaw while maintaining wing 120 stable at any angle with respect to any axis. By pulling on one or more cables 138, control mechanism can tilt wing 120 in any direction. Releasing (unspooling) cable 138 enables mast 114 (retracted by pull of cable 138) to extend out via the spring or hydraulic mechanism described above to any set height and wing 120 angle.

In order to tack wing 120, control mechanism pulls cables 138 to swing wing 120 from an upright position on one side of mast assembly 102 to the opposite side while mast assembly 102 swivels to correctly align wing 120 to the desired angle of attack with respect to the wind. This roll and yaw movement is similar to that described above for system 10.

Systems 10 and 100 can also include any number of sensors for providing an operator with information relating to the position of wing 12 or 120, the vessel, as well as environmental information. Table 2 below describes sensors that can be used with the present invention and their location in systems 10 or 100.

Table 2

No.	Sensor	Units	Location
1.	Sailing azimuth	Degrees	Ship bridge or vessel GPS
2.	Apparent Wind direction	Degrees	at wing center on leading edge
3.	Apparent Wind speed	Meter/second	at wing center on leading edge
4.	Swiveling base level relative to see level	Degrees	On swiveling base
5.	Base center line angle relative to (1)	Degrees	On swiveling base
6.	Masts angle relative to Swiveling base level	Degrees	On bottom section of 1 mast
7.	Mast 1 length	Meter	On top of mast 1
8.	Mast 2 length	Meter	On top of mast 2
9.	Mast 3 length	Meter	On top of mast 3
10.	Mast 4 length	Meter	On top of mast 4
11.	Wing roll angle relative to see level	Degrees	Beneath wing C.G
12.	Angle of attack - Angle between base (5) and apparent wind direction (2)	Degrees	Beneath wing C.G pointing to leading edge

Such sensors enable an operator to correctly position wing 12 or 120 with respect to the wind and thus maximize a propulsive force obtained from wing 12 or 120 with respect to a moving direction of the craft.

A typical sensor reading scenario is described in Table 3 below.

Table 3

No.	Sensor	Units	Reading
1.	Sailing azimuth	Degrees	80
2.	Apparent wind direction	Degrees	340
3.	Apparent Wind speed	Meter/second	11
4.	Swiveling base level relative to see level	Degrees	0.5
5.	Base center line angle relative to (1)	Degrees	-82
6.	Wing roll angle relative to see level	Degrees	80
7.	Angle of attack	Degrees	18

Systems 10 and 100 further include a control unit (not shown), preferably positioned in the cockpit on the bridge. The control unit includes a user interface for controlling control mechanism 32 or 132 and for obtaining information related to a state of wing 20 or 120 (e.g. from above describe sensors), masts 14 or 114, swiveling base 18 or 118 and any other component of system 10 or 100. The control unit is wired to control mechanism 32 or 132 or is wirelessly connected thereto via an RF communication module.

The control unit can operate in an open loop mode, in which case relevant information (from the sensors) is displayed to an operator which then modifies wing 20 or 120 position accordingly, or it can operate in a closed loop mode (auto-pilot) in which case, the computer of the control unit will make decision based on sensor data and course plotted. In the closed loop mode, the operator can override computer control at any point in time. Figure 8 illustrates closed loop control over wing 20 or 120 and base 18 or 118 based on sensor data.

The control unit can include a touch screen display (e.g. a capacitive display) for providing an operator with graphic or textual information relating to wing 20 or 120 (position, angles etc) and the angle of base 18 or 118 with respect to the wind and sailing direction.

Any number of system 10 assemblies can be used on a craft. For example, a large water craft such as a tanker (Figures 7a-b) can utilize several system 10 or 100 assemblies (9 shown), each having a dedicated control mechanism 32 or 132. Alternatively, one or more control mechanism 32 or 132 can be used to control several

mast/wing assemblies. In any case, control mechanism(s) 32 or 132 are preferably each controlled via a single control unit which can also retrieve and display to an operator sensor reading from each mast/wing assembly.

When utilized for propulsion in a water craft such as a 200,000 ton tanker (Figures 7a-b) a wing having 600 m² can provide, in case of CL_{max} 4.5 and apparent wind velocity of 10 m/s (19.4 Knot) from a beam and air temperature 10⁰, a propulsive force of 169,000 Newton (N). Thus, ten such system 10 or 100 assemblies (Figures 7a-b respectively) can provide a propulsive force of 1,690,000 N which can lead to considerable savings in fuel.

Systems 10 or 100 of the present invention can be retrofitted onto any water/land craft or it can be added to the craft during fabrication thereof (in a ship-building yard). Swiveling base 18 or 118 includes a ring which that is mounted on bearings connected to the deck through rods (welded or bolted to deck). The ring diameter equals the swiveling base 18 or 118 diameter. Motors located on base 18 or 118 rotate a gearwheel engaged to the ring or deck. On a small maritime vessel (e.g. yacht) one wing type sail system 10 or 100 will be mounted at around 30% of its length towards bow. On larger vessels 2 – 20 systems 10 or 100 can be mounted along longitudinal center line, in one or more parallel longitudinal rows. For example system 10 or 100 with 500m² wing 20 or 120 area will be mounted for each 20K tons of a big ship in 2 parallel longitudinal rows with 100% (or more) of wing span clearance between each system 10 or 100 (Figures 7a-b respectively).

When used in large sea going freighters or tankers, the operation of system 10 or 100 can be synchronized with the propulsion system of the ship and with weather conditions while considering costs, voyage timeline and on-time arrival at harbors.

Since on-time arrival at harbors is critical especially for cargo ships, efforts are made to maintain an average planned speed. Contribution of wind propulsion generated by the present invention to the power needed to maintain that speed can vary between 0% and 100% depending upon wind speed and direction along the route. Wind conditions depend on dates, seasons and global location. In head winds between 30⁰ and -30⁰ there is no contribution of wind power. In apparent wind angle of 90⁰ or -90⁰, wind speed in excess of 12m/s and vessel's planned speed of 14 Knots the wind propulsion could provide 80% - 100% of the power needed. The perfect angle of the wings relative

to the wind is automatically and continuously controlled by a control unit of the present invention (receiving input from sensors - wind direction and speed, vessel's sailing direction) and produce output to activate electro mechanical units that maneuver the wings. Any voyage is planned in advance according to weather conditions along the planned route at the planned dates, and the amount of fuel needed (or saved) is calculated automatically computationally.

As used herein the term "about" refers to $\pm 10\%$.

Additional objects, advantages, and novel features of the present invention will become apparent to one ordinarily skilled in the art upon examination of the following examples, which are not intended to be limiting.

EXAMPLES

Reference is now made to the following examples, which together with the above descriptions illustrate the invention in a non limiting fashion.

EXAMPLE 1

Model boat with a wing sail system

Figure 9 is an image of a model boat fitted with a prototype system 100. The model is a 1 meter mono hull built from Styrofoam reinforced with aluminum bars. The model has a large hydrodynamic keel made of iron and is covered by a smooth sheet of stainless steel and includes a rudder made of aluminum pole and stainless steel sheet. The prototype wing sail system includes 2 parallel masts built from welded aluminum poles. The mast assembly can rotate 180° clockwise or counterclockwise around the center mast which is inserted into the hull. The wing span is 1.45 meters, and has an aspect ratio of 10; it is fabricated from condensed Styrofoam laminated with fiberglass. The wing is connected to the masts by horizontal axis allowing it to rotate 180° clockwise or anti clockwise. Rudder, masts assembly rotation and wing angles (via ailerons) are all remote controlled.

The model was tested in a 400 X 100 meters pool, in an 18 knots northwest wind. During the test the model was sailed in various directions with generally satisfying results.

EXAMPLE 2***Catamaran with a wing sail system***

A 4 hull catamaran fitted with system 10 was designed (Figure 10a) and constructed. A fifth hull (arrow in Figure 10b) was added to the prototype during
5 construction in order to better support the weight of the mast assembly and wing. The hulls were fabricated from fiberglass and reinforced aluminum struts and assembled to form a catamaran that is 4.4 meters wide and 7.2 meters long (Figure 10d). A 1.9 m swiveling base was fabricated from stainless steel; the base swivels on 8 pairs of bearings. The mast assembly was constructed from stainless steel struts connected via
10 pins and hinges to 6 points on the swiveling base. The mast assembly is 1.86 meters in diameter and 4.20 meters in height.

The wing-type sail (Figure 10c-d) includes a main airfoil element and a trailing edge winglet (Figure 10e). The wing was fabricated from 40 airfoil sections of aluminum and birch 'sandwiches'. The overall length of the wing is 7.96 meter and the
15 width is 1.32 meter. The prototype catamaran was tested successfully in a 7 knot wind (Figure 10d).

It is appreciated that certain features of the invention, which are, for clarity, described in the context of separate embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the invention, which are, for
20 brevity, described in the context of a single embodiment, may also be provided separately or in any suitable subcombination.

Although the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, it is intended to embrace all
25 such alternatives, modifications and variations that fall within the spirit and broad scope of the appended claims. All publications, patents and patent applications mentioned in this specification are herein incorporated in their entirety by reference into the specification, to the same extent as if each individual publication, patent or patent application was specifically and individually indicated to be incorporated herein by
30 reference. In addition, citation or identification of any reference in this application shall not be construed as an admission that such reference is available as prior art to the present invention.

WHAT IS CLAIMED IS:

1. A wing-type sail system comprising:
 - (a) a mast assembly pivotally mounted on a swiveling base attachable to a craft;
 - (b) a substantially rigid wing pivotally attached to a top of said mast assembly, said wing having an asymmetric profile; and
 - (c) a control mechanism for modifying a roll and yaw of said substantially rigid wing with respect to the craft.
2. The system of claim 1, wherein said wing is pivotally attached to a top of said mast assembly at a central portion thereof.
3. The system of claim 1, wherein said mast assembly forms a triangular tower.
4. The system of claim 1, wherein said wing is oriented to wind side by rolling said wing and rotating said swiveling base.
5. The system of claim 3, wherein a top of said triangular tower is attached to said wing through a pin-type hinge.
6. The system of claim 1, wherein said mast assembly includes a plurality of mast poles each being separately connected to said swiveling base and said wing.
7. The system of claim 1, wherein said control mechanism includes control wires for modifying said roll and yaw of said wing.
8. The system of claim 2, wherein said control mechanism is further capable of modifying a height or pitch of said wing.
9. The system of claim 6, wherein a length of each of said plurality of mast poles is telescopically adjustable.

10. The system of claim 1, wherein said wing is pivotally attached to said mast assembly around a center of gravity of said wing.

11. The system of claim 1, further comprising wind speed and direction sensors mounted on said mast assembly and/or on said wing.

12. The system of claim 1, further comprising a level angle sensor mounted on said swiveling base.

13. The system of claim 1, further comprising a control unit for actuating said control mechanism according to information selected from the group consisting of wind speed, wind direction, vessel longitudinal direction, a level angle of said swiveling base, and an angle of said roll and yaw of said substantially rigid wing.

14. The system of claim 1, wherein said wing is foldable.

15. The system of claim 14, wherein said wing is telescopically foldable.

16. The system of claim 13, wherein said control unit is wired to said control mechanism.

17. The system of claim 13, wherein said control unit wirelessly communicates with said control mechanism.

18. The system of claim 1, wherein said wing includes a trailing edge extension and/or a leading edge.

19. The system of claim 18, wherein said trailing edge extension is shaped as a winglet and said leading edge extension is shaped as a slat.

20. The system of claim 19, wherein said winglet has an asymmetric profile.

21. A vessel comprising a plurality of the systems of claim 1.
22. The vessel of claim 21, wherein the vessel is a cargo ship, a tanker, a cruise liner or a yacht.
23. The vessel of claim 21, further comprising a control unit for controlling each control mechanism of said plurality of systems.

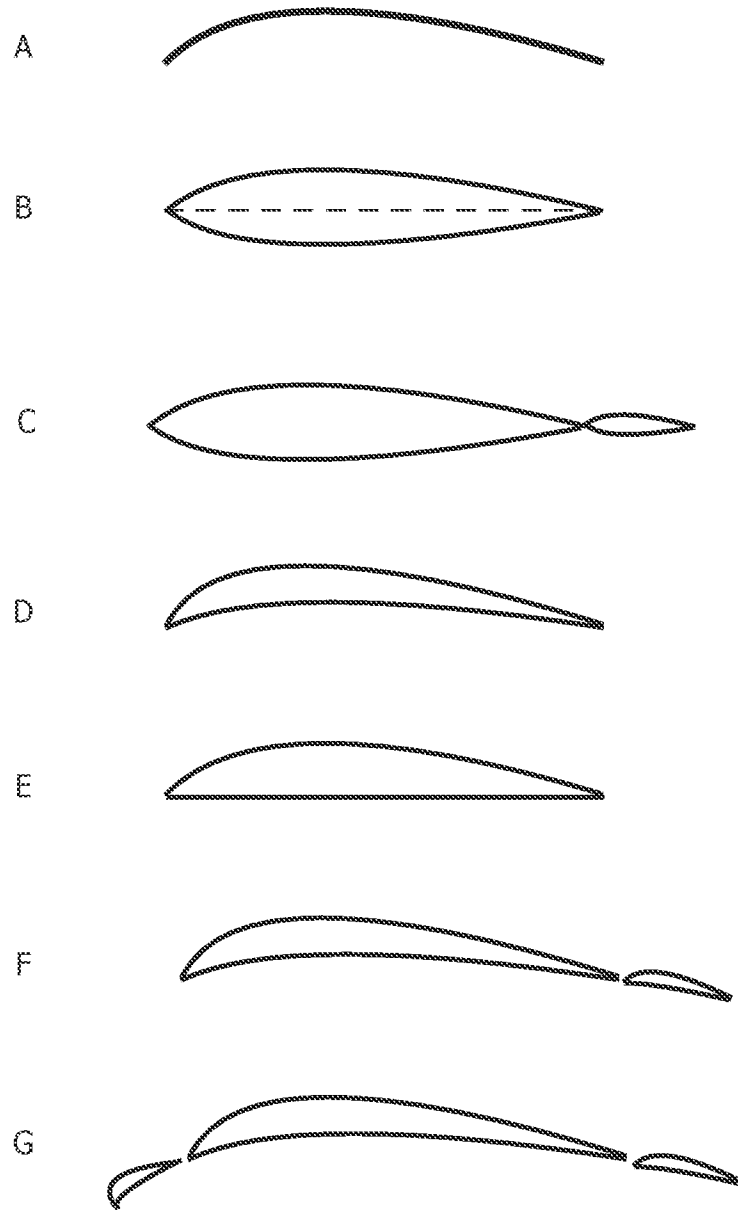


FIG. 1

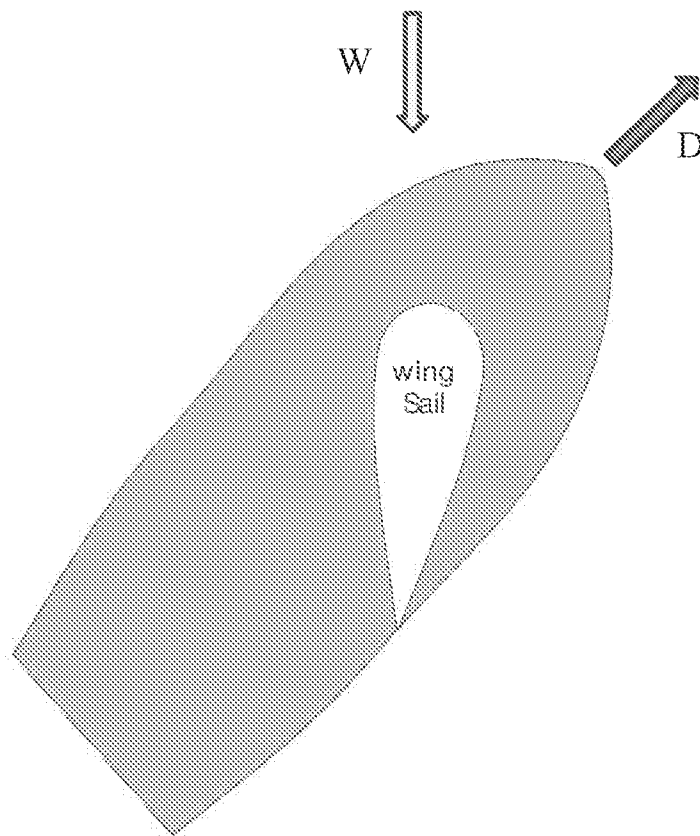


FIG. 2a

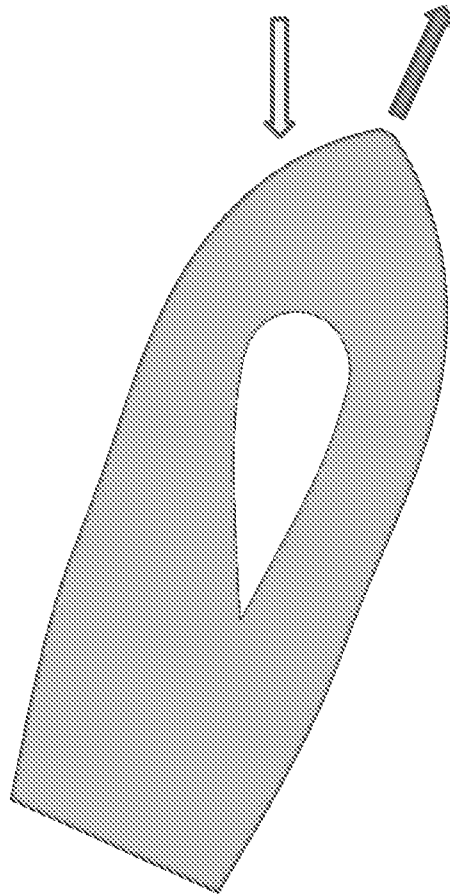


FIG. 2b

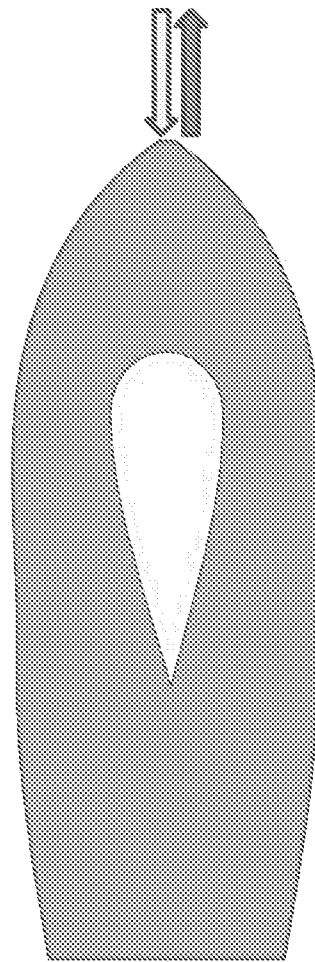


FIG. 2c

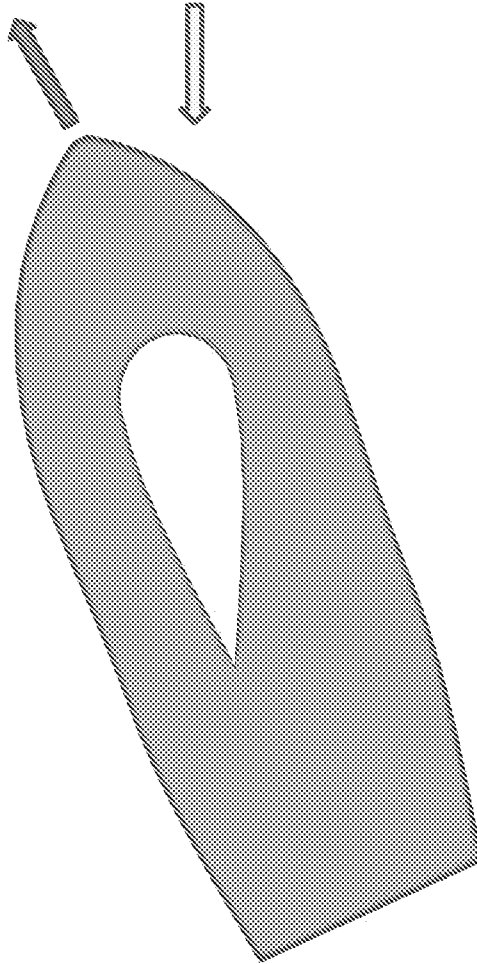


FIG. 2d

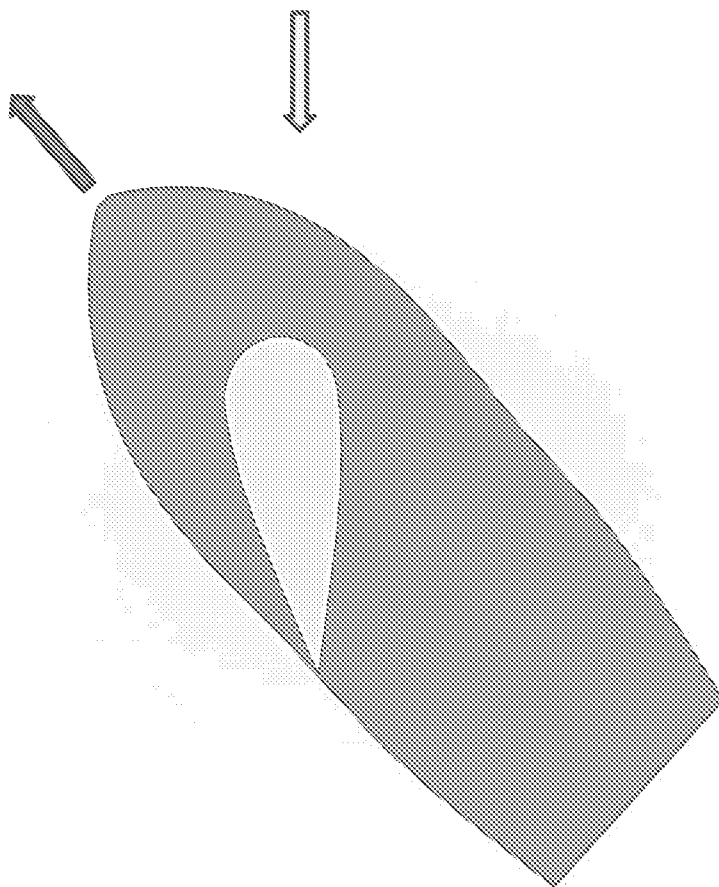


FIG. 2e



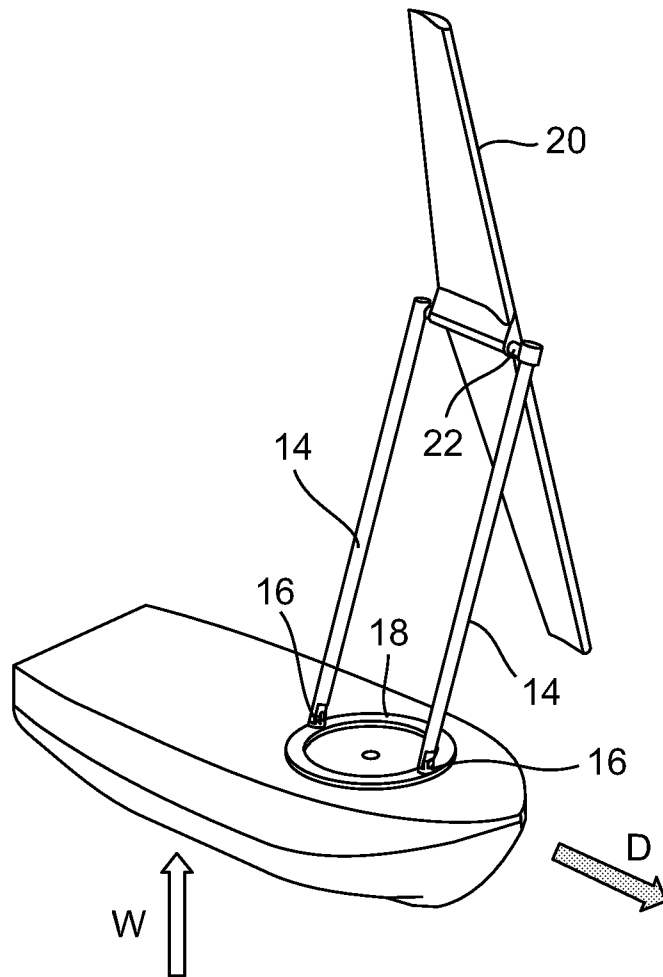


FIG. 4a

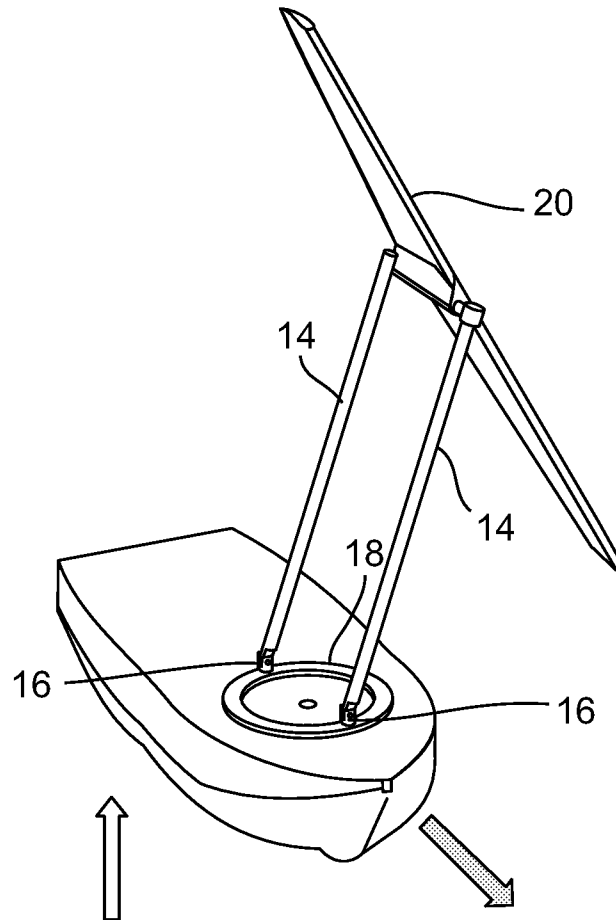


FIG. 4b

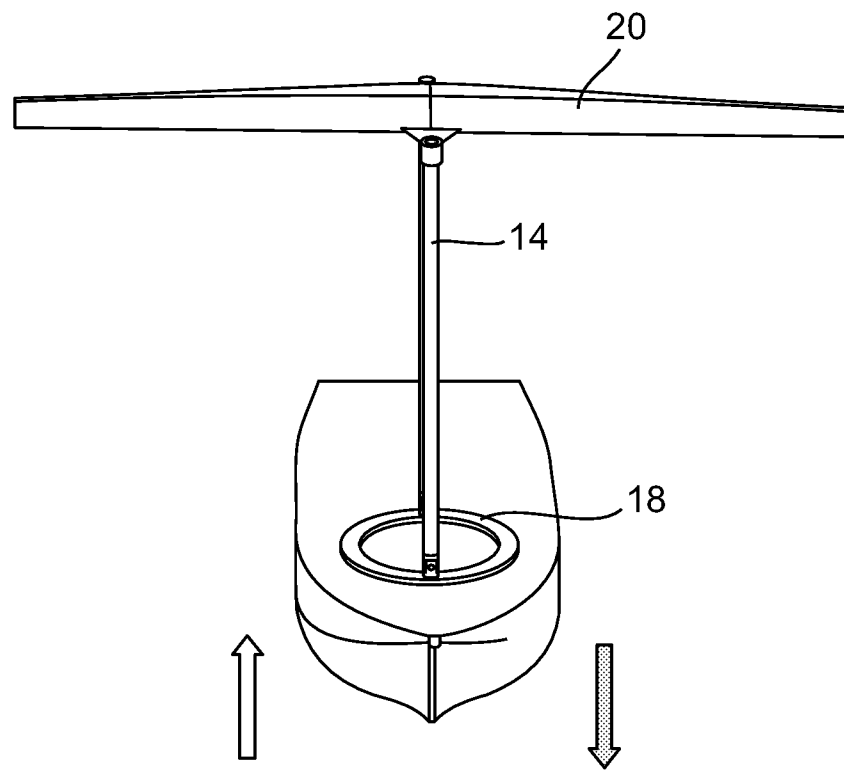


FIG. 4c

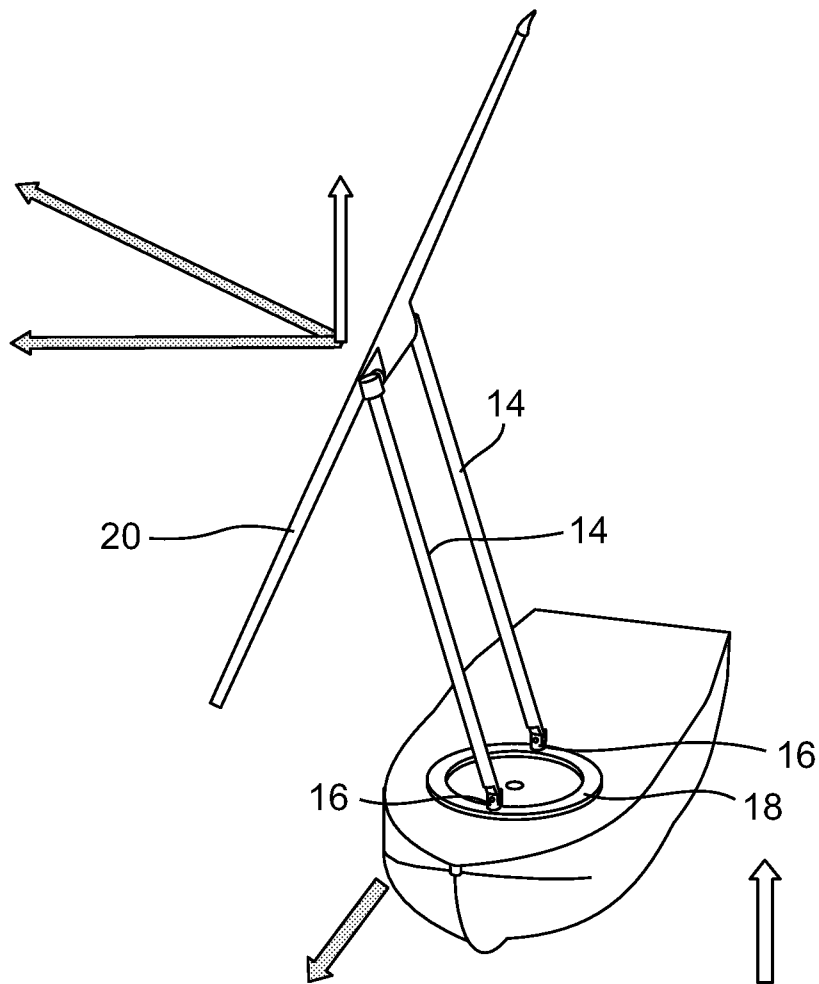


FIG. 4d

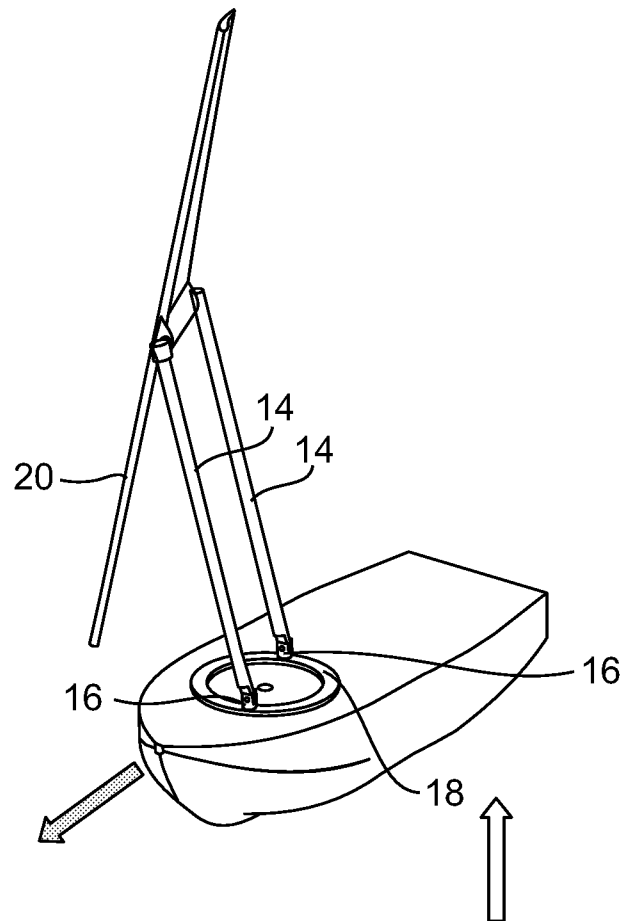


FIG. 4e

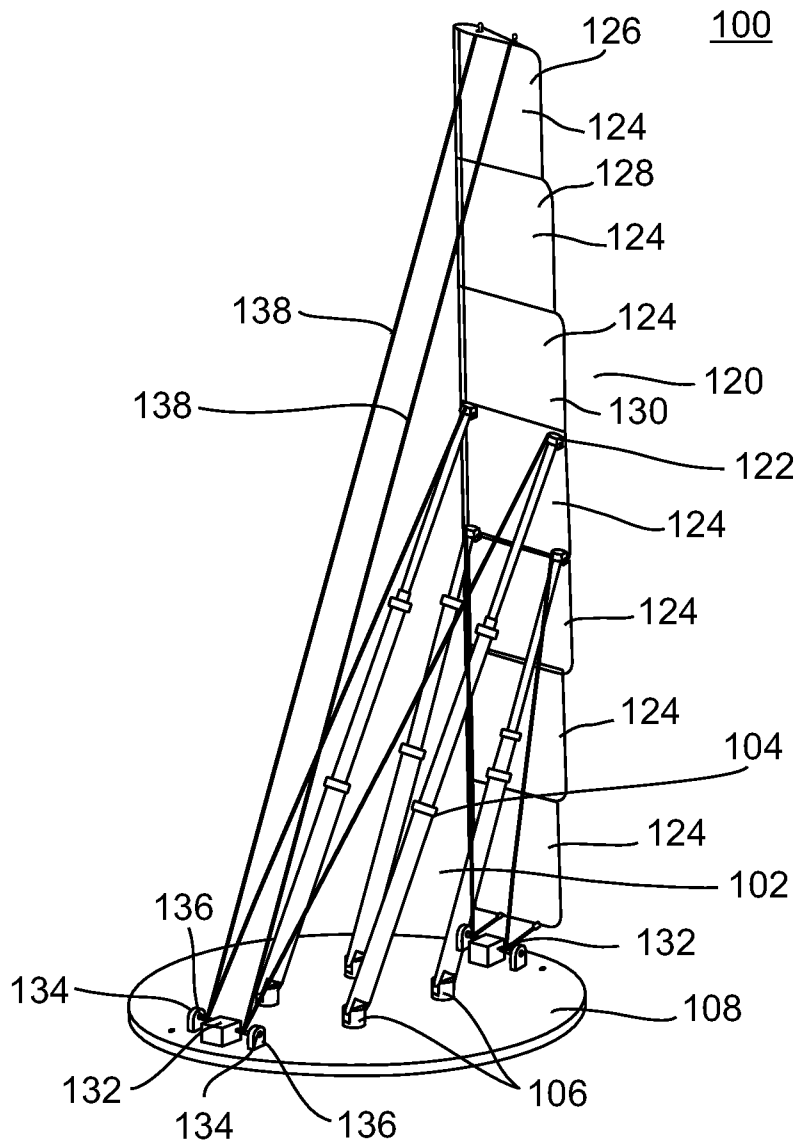


FIG. 5

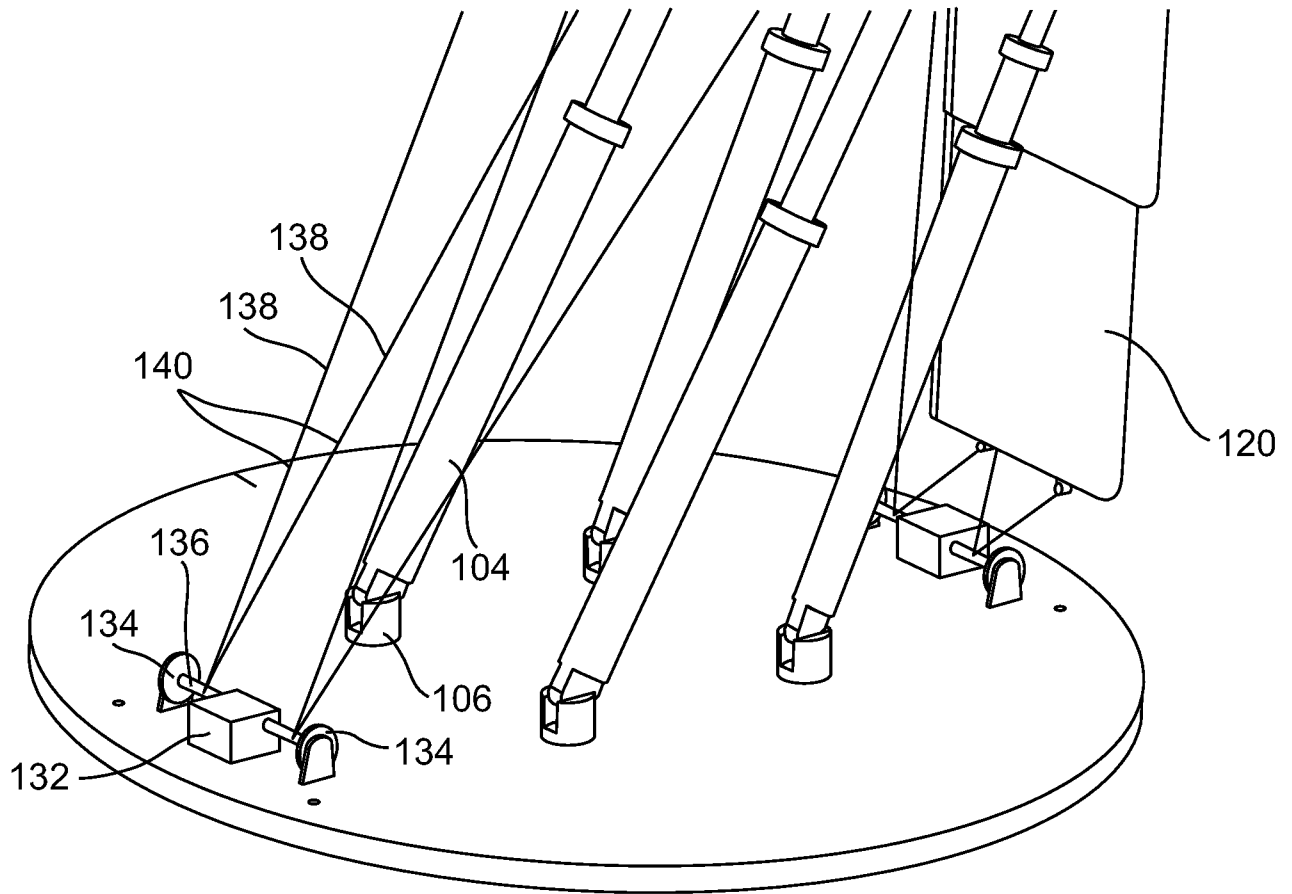


FIG. 6

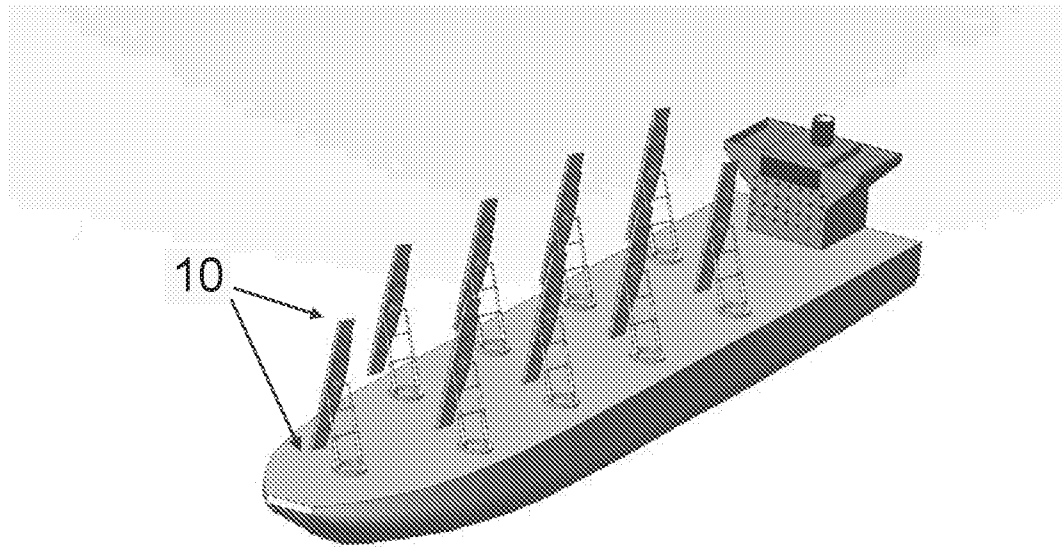


FIG. 7a

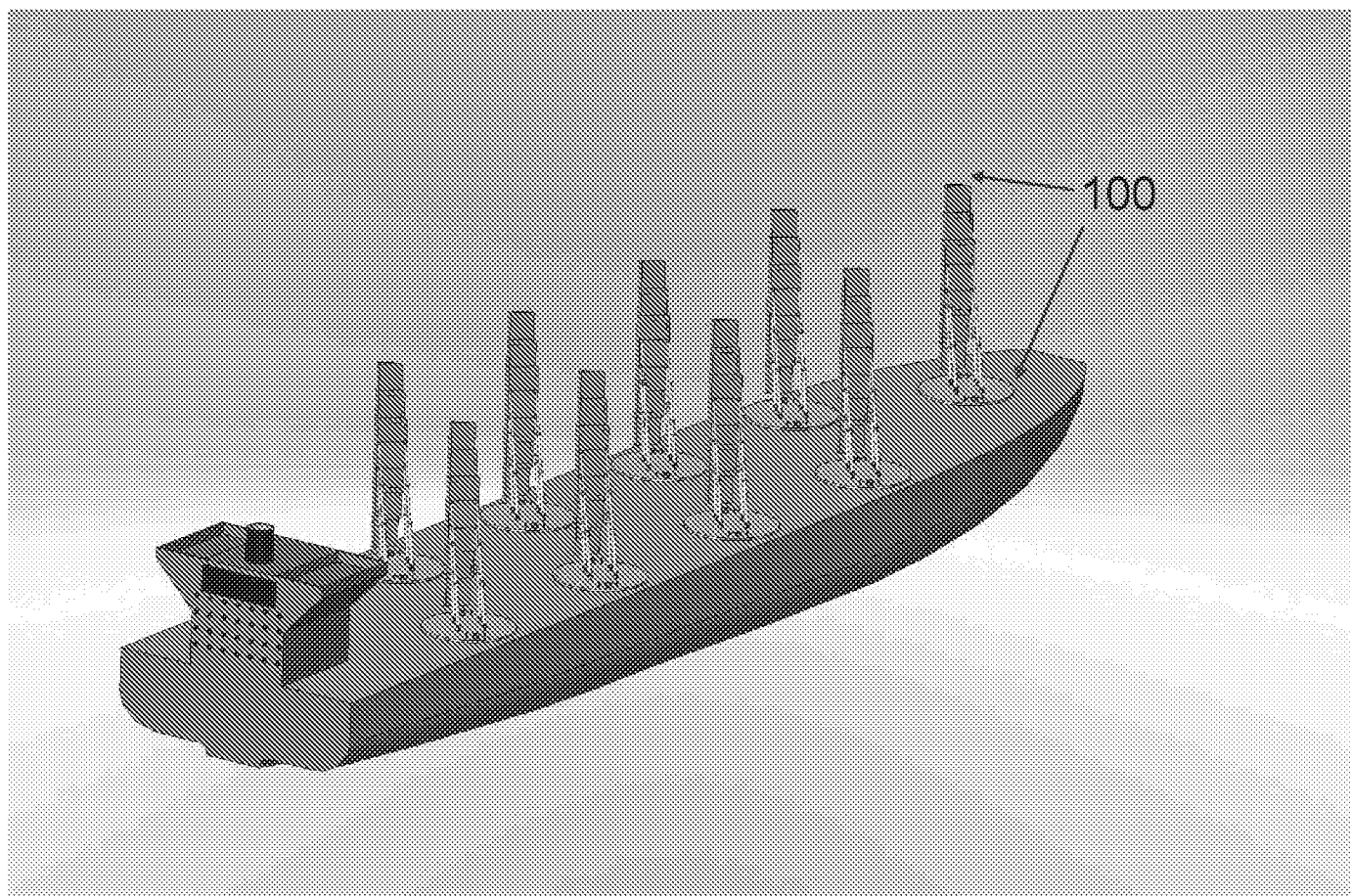


FIG. 7b

FIG. 8

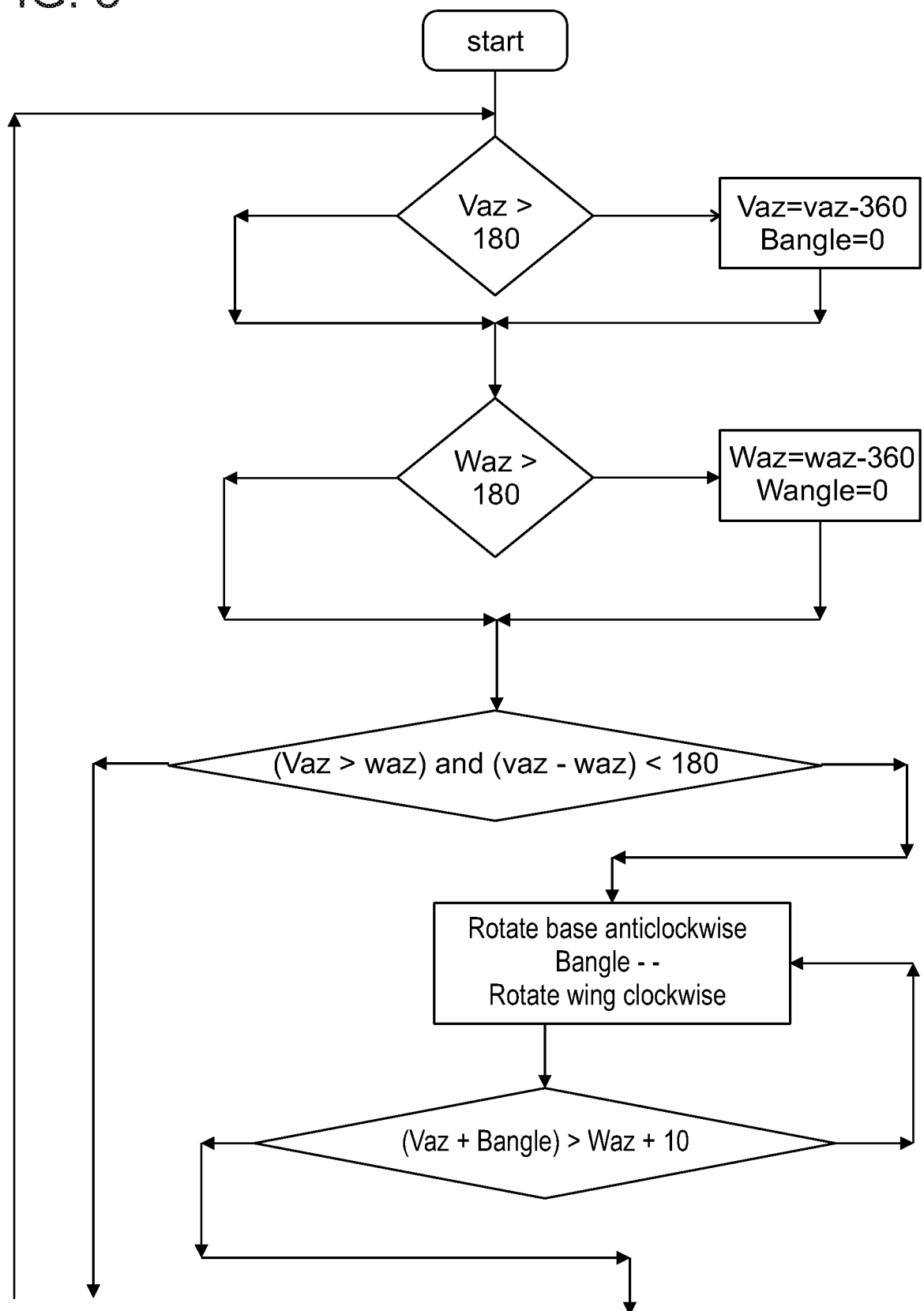
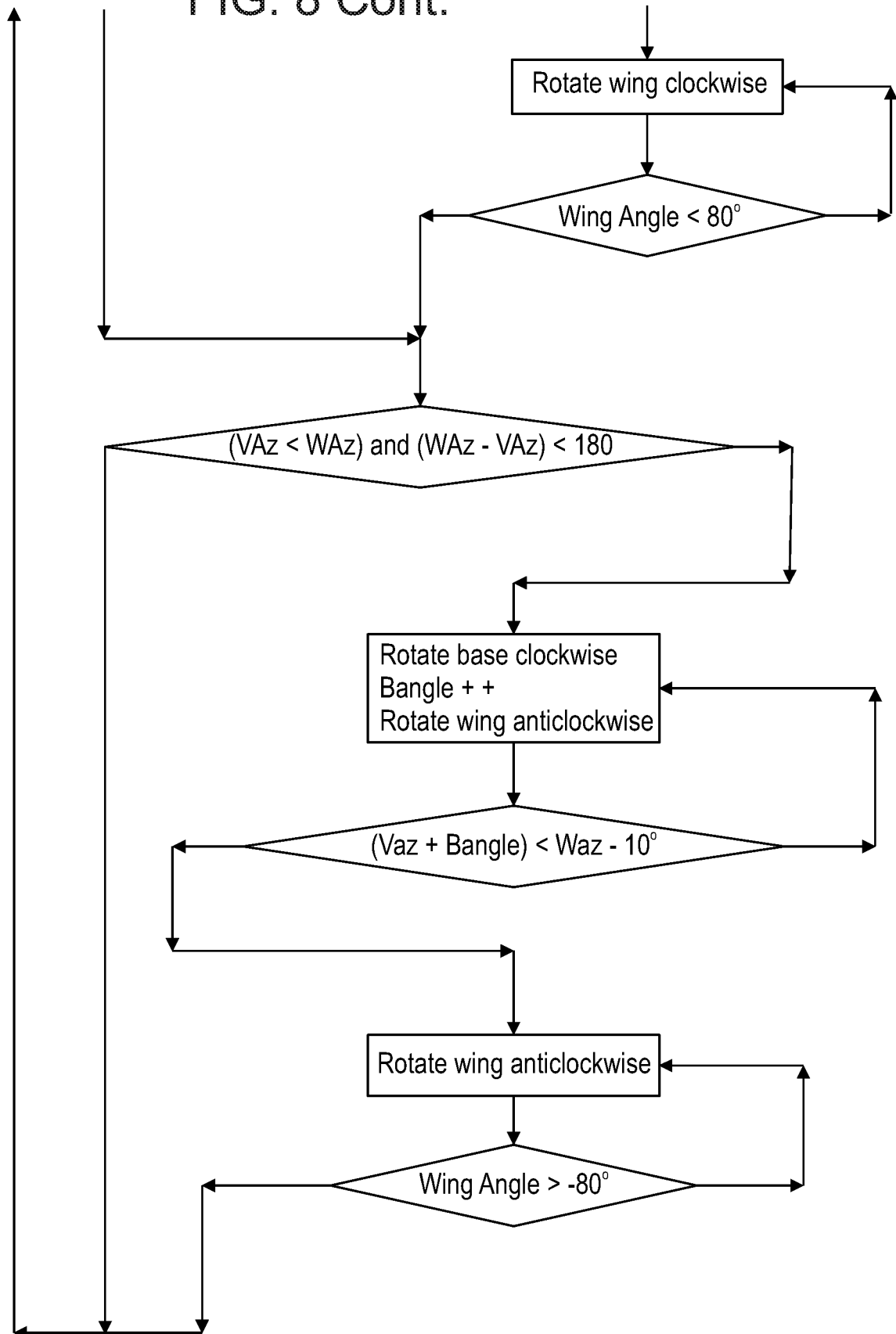


FIG. 8 Cont.



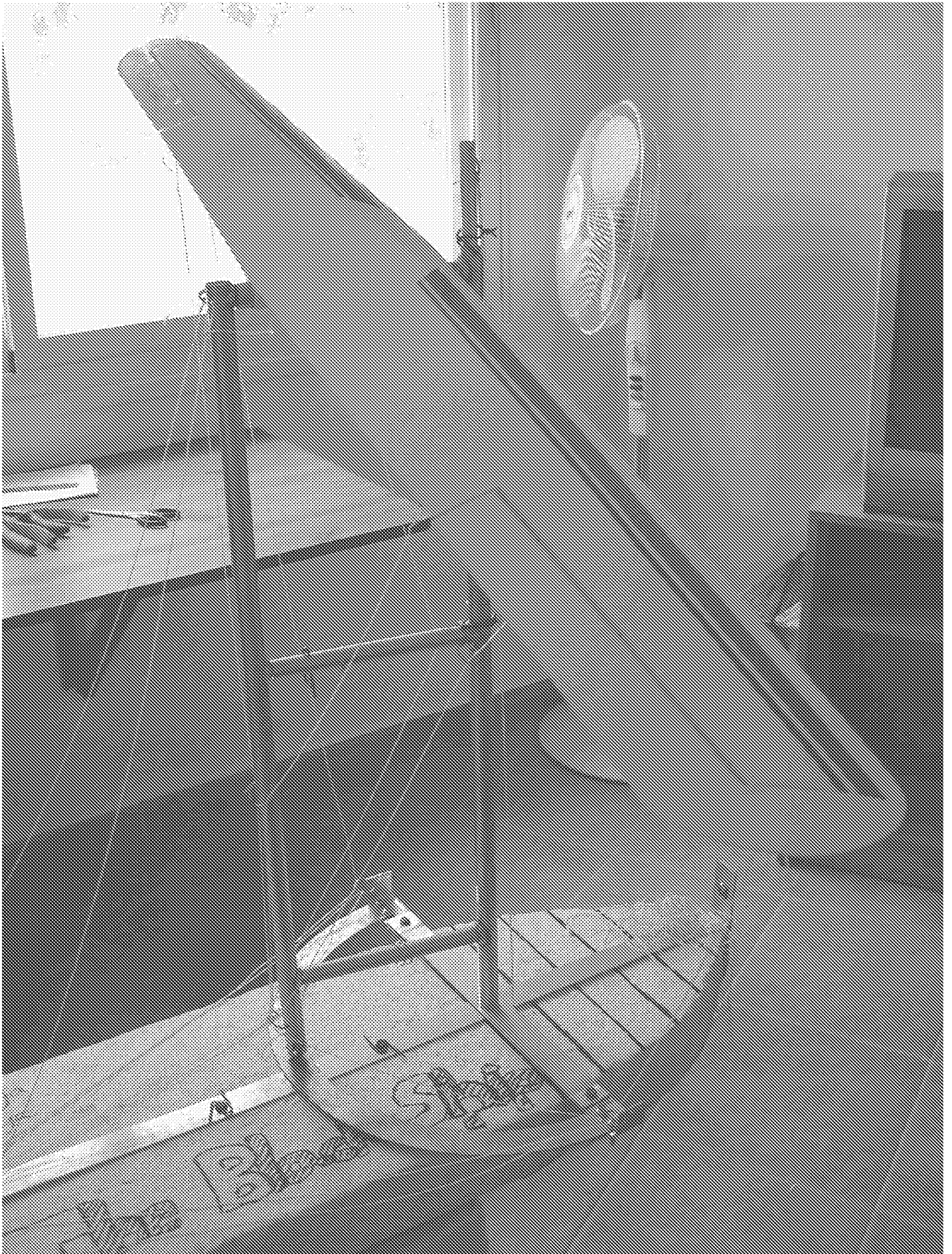


FIG. 9

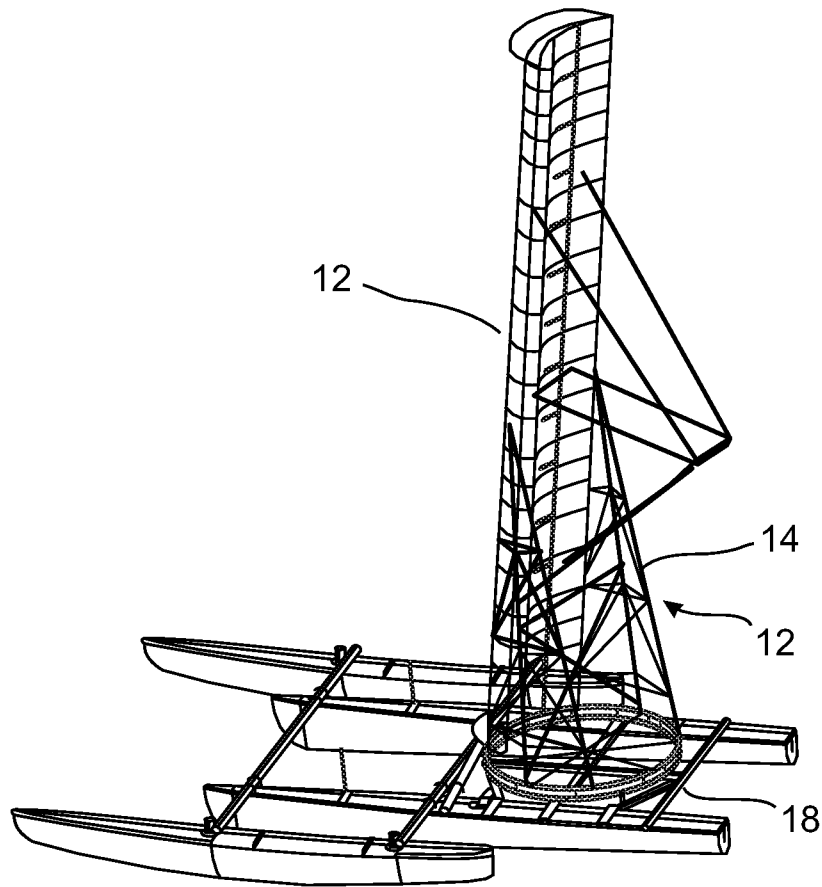


FIG. 10a

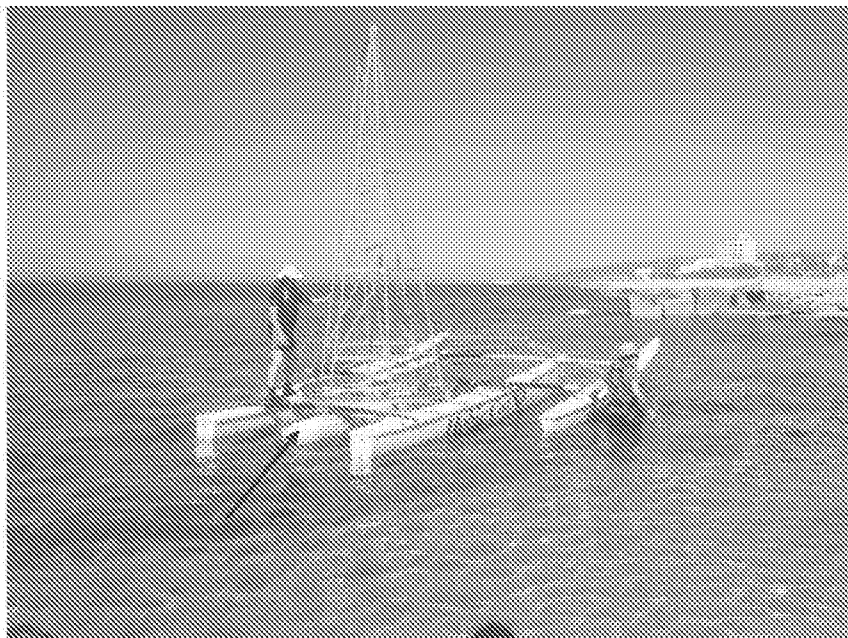


FIG. 10b

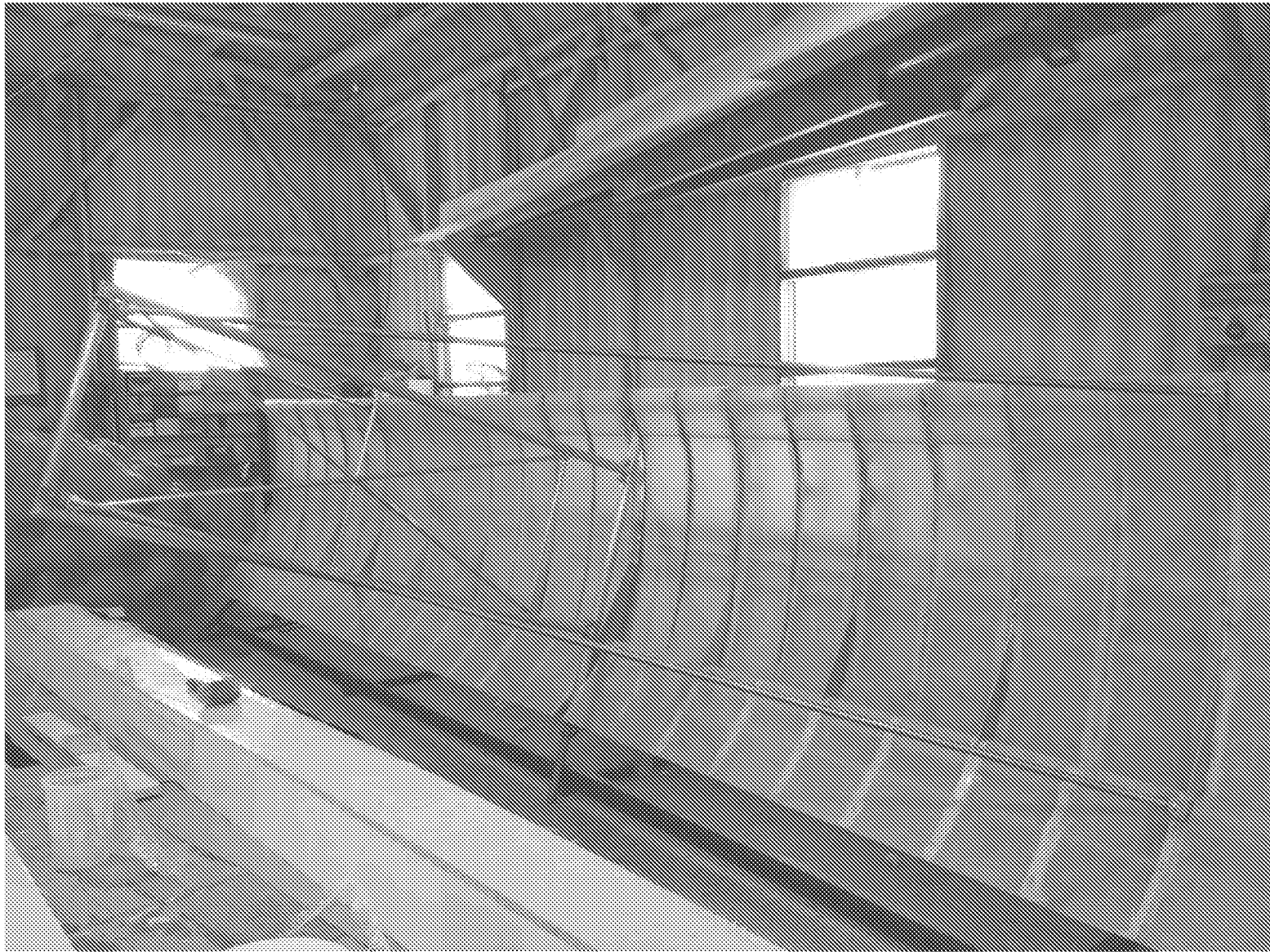


FIG. 10c



FIG. 10d

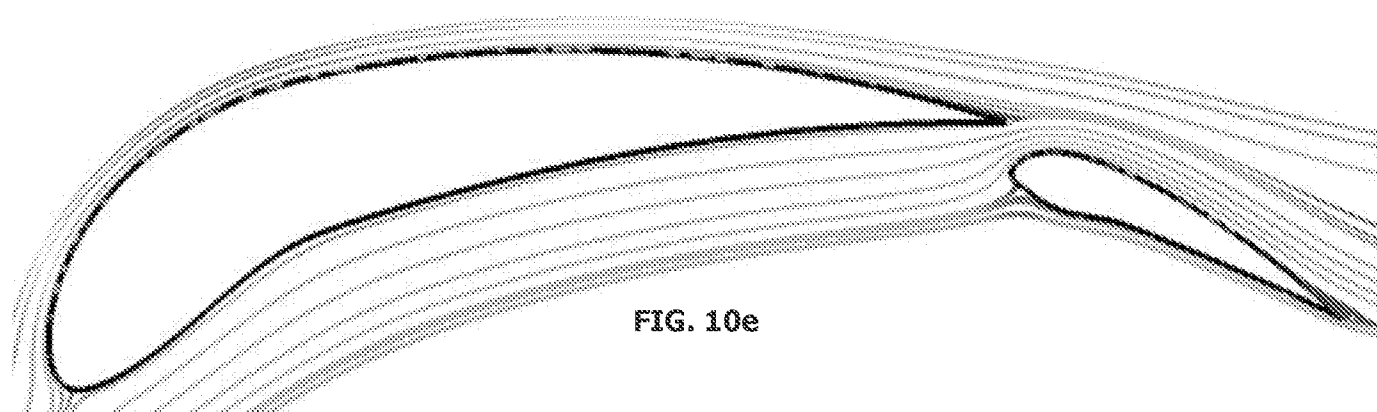


FIG. 10e

INTERNATIONAL SEARCH REPORT

International application No.

PCT/IL 16/50716

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - B63H 9/06, B63H 9/04, B63H 9/00 (2016.01)

CPC - B63H 9/06, B63H 9/0607, B63H 2009/0621, B63H 2009/0628, B63H 9/04, B63H 9/00

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)

IPC(8): B63H 9/* (2016.01)

CPC: B63H 9/*

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

IPC(8): B63H* (2016.01)

CPC: B63H*

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

PatBase, Google Patents, Google Web

Keywords: airfoil, aerofoil, wing, mast, sail, control, yaw, roll, pitch, sensor, wireless, remote, speed, sensor, velocity, direction, swivel

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y -- A	DE 8509163 U1 (CRAMER) 31 July 1986 (31.07.1986), entire document	1-2, 4, 6-18, 21-23 ----- 3, 5, 19-20
Y -- A	US 4,682,557 A (MAGRUDER et al.) 28 July 1987 (28.07.1987), entire document	1-2, 4, 6-18, 21-23 ----- 3, 5, 19-20
Y	US 4,671,201 A (YOKOYAMA) 09 June 1987 (09.06.1987), entire document	11-13, 16, 17
Y	US 4,685,410 A (FULLER) 11 August 1987 (11.08.1987), entire document	14-15
A	DE 29501822 U1 (MADER ANTON DIPL ING) 27 April 1995 (27.04.1995), entire document	1-20
A	US 2002/0100406 A1 (COSTA, Jr. et al.) 01 August 2002 (01.08.2002), entire document	1-20
A	WO 90/02683 A1 (D'ORSO) 22 March 1990 (22.03.1990), entire document	1-20
A	GB 1184914 A (GALBERT) 18 March 1970 (18.03.1970), entire document	1-20

☐ Further documents are listed in the continuation of Box C.

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"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

07 October 2016

Date of mailing of the international search report

24 OCT 2016

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