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(54) **MONOHULL SAILING BOAT PROVIDED WITH HYDROFOILS, IN PARTICULAR FOR SAILING COMPETITIONS**

(57) A monohull sailing boat (1), in particular for sailing competitions, has a hull (2) with a bow (4), a stern (5) and two sides (11) opposite each other; the hull extends along a longitudinal axis (3) and supports two side arms (10), which are arranged at the two sides (11), each have a respective first hydrofoil (12) and are movable between a retracted position and an at least partially deployed position under the action of a movement system; at the stern, the boat (1) has a rudder (44) and a second hydrofoil (46), arranged centrally between the two sides (11); in addition, the boat (1) has a keel (23), which projects downwards from an intermediate portion (25) of the hull (2) between the stern and the bow and carries a third hydrofoil (28) projecting transversely; the lift of the hydrofoils (12,46,28) is adjustable by means of respective actuators (18,47,30) which are independent of each other and can be operated in a coordinated manner.

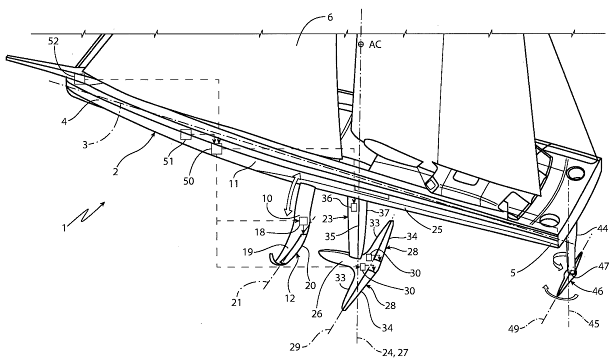

FIG.1

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Description

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This patent application claims priority from Italian patent application no. 102023000017682 filed on August 29, 2023, the entire disclosure of which is incorporated herein by reference.

TECHNICAL FIELD

[0002] The present invention relates to a monohull sailing boat provided with hydrodynamic load-bearing wings, usually referred to as "hydrofoils", or more simply "foils", which are configured to have a hydrodynamic lift that is able to support the weight of the boat and keep the hull out of the water when the boat is sailing at relatively high speeds.

[0003] In particular, the present invention relates to a monohull sailing boat for sailing competitions, which usually require a dedicated design in order to be able to maximize the speed achieved by the boat.

PRIOR ART

[0004] Hydrodynamic load-bearing wings, or hydrofoils, have long been known to be mounted on boats in order to keep the hull of the boat out of the water when certain cruising speeds are reached, in a condition commonly referred to as "planing condition", in order to reduce hydrodynamic resistances during navigation.

[0005] In recent decades, hydrofoils have also been used in the sailing boat sector, both on multihull type boats, in particular trimarans, and on monohull type boats, with the aim of maximizing the speed in boats designed for sports competitions.

[0006] For this purpose, when the number of hulls can be selected, it is preferable to adopt monohull boats, since multihull boats have a relatively large frontal area, orthogonally to the direction of navigation, and therefore offer substantial aerodynamic resistances at the speeds reached in the planing condition, in particular resistances commonly referred to as the "windage".

[0007] Another important aspect for ocean-going vessels is static stability, which is their ability to self-right in the event of a partial (less than or equal to 90°) or total (180°) capsizing following unexpected events related to the wave motion or the wind. In this regard, multihull boats are generally not self-righting, neither in case of partial capsizing (90°), nor in case of total capsizing (180°). It is therefore essential that, in the event of adverse conditions, the captain keeps the vessel at an appropriate distance from the stability limit.

[0008] Finally, large ocean-going catamarans tend to have difficulty in managing their planing in very rough seas, where the two hulls of the catamaran, more than twenty meters apart, are involved in distinct, potentially counter-phase, wave systems, which require speed reduction.

[0009] With regard to monohull sailing boats, from the point of view of speed, the solutions that were adopted in the regattas of the sailing competition called "America's Cup" in the year 2021 proved to be very performing. In particular, speeds as high as around 50 knots (93 km/h) could be reached in the planing condition.

[0010] Yachts of this type, also referred to as AC75 class yachts, are equipped with two arms which are arranged, respectively, on the opposite sides of the hull, are provided with respective hydrofoils and are movable, each independently of the other, between a raised position and a lowered position. To sail in the planing condition, only one of the two side arms is lowered, i.e. the downwind one, with its hydrofoil submerged in the water to balance, practically on its own, the weight of the boat and the capsizing or heeling torque (usually referred to as the "heeling moment") due to lateral wind forces on the sails.

[0011] Indeed, another hydrofoil is also provided, usually referred to as the "elevator", arranged in a central position at the rudder, at the stern of the boat; however, the hydrodynamic lift of this hydrofoil is relatively low and cannot support the weight of the boat, but is used to control the pitch.

[0012] This type of boat, while having very high performance, is suitable only for sailing in inshore conditions, i.e. close to the coast and/or in protected bays where the sea is relatively calm and the wind is contained within a certain range of acceptability (established by the competition rules).

[0013] In particular, when sailing at high speeds with the hull out of the water, the balance of forces is dynamically stable only in a very narrow range of use, especially because the weight of the boat and the heeling moment exerted by the wind are essentially balanced by a single hydrofoil, the one arranged at the lowered side arm. As a result, controlling the boat and the balance of forces as external conditions vary is relatively complex, and must be performed very frequently, especially as regards the sails.

[0014] For example, to compensate for the inevitable changes in wind, manual corrections are often made on the sails. Let's assume that the boat is sailing upwind (against the wind) and that it is in an optimal condition (i.e. with full sails), with the hull raised to a desired height with respect to the free surface of the sea: the lift of the hydrofoil of the side arm submerged in the water balances the weight of the boat and, at the same time, provides a righting torque (referred to as the "righting moment") that balances the heeling moment exerted by the wind on the sails. Let's then assume that the wind increases in intensity: the sails will be subjected not only to an increase in thrust along the navigation direction, but also to an increase in the lateral force component, with a consequent increase in the heeling moment: to rebalance the boat, the sails are acted upon to restore the lateral load level to the value before the gust. Normally, the lift of the hydrofoil submerged in the water is not adjusted as often as the sails and rudder are adjusted to react to wind disturbances, as this adjustment would affect the vertical balance of the boat's weight, with an undesirable change in hull height relative to the free surface of the sea (hence with a deviation from the optimal conditions).

[0015] Let's instead assume that the wind drops in intensity: this drop leads to a decrease in the heeling moment: in this case, to restore the balance, the lift of the hydrofoil submerged in the water and the angle of rotation of the arm supporting this hydrofoil are normally acted upon jointly to set the correct righting moment without compromising the balance in the vertical direction.

[0016] Adjustments of this kind are effective but very energyconsuming, because they are relatively complex to perform, they do not always achieve a timely result in balancing the boat, and they can reduce the thrust component along the navigation direction.

[0017] In addition, adjustments are repeated very frequently, mainly manually, and have a limited range (i.e., limited correction capacity), so they are only suitable for short stretches of navigation and, as mentioned above, in inshore conditions, where the wind and sea must be within a certain range for the race to start. In offshore conditions, i.e. on the high seas, wind and wave conditions are much broader and, in general, can become challenging to balance the boat in the manner described above, so different or additional measures should be taken.

[0018] In addition, AC75 class yachts are self-righting only in the event of a partial capsize with capsize angles of less than 90°, while they are not self-righting in the event of a total capsize. In this regard, sailing boats are known which, in addition to having the side arms with the hydrofoil, are equipped with a keel with a bulb, below the hull in a central position, to improve the stability of the boat and make it self-righting in case of a total capsize. For example, IMOCA 60 class boats are of this type, but they do not have the possibility of continuously adjusting the lift of their hydrofoils and do not have a hydrofoil elevator. For the latter aspect, this class of boats has a relatively high hydrodynamic resistance: in fact, part of the hull is always submerged in the water in order to manage the pitch, given the lack of a rear elevator, so they are unable to achieve an actual planing condition for extended periods of time.

[0019] Although the rules of this class do not allow the use of an elevator, there is however a known evolution in which a boat of this type has been equipped with a fixed (nonadjustable) surface to control the pitch, resulting in enhanced stability of the planing condition in calm sea conditions. In this regard, the internet page at the following link can be consulted: https://www.solovela.net/notizie/3/louis-burton-imoca/1351822/

[0020] Finally, an exploratory project is known for the introduction of a new class of ocean monohulls for the "Volvo Ocean Race" competition, which presented a study of a boat with an elevator equipped with adjustable "flaps" (to manage the pitch dynamically). In this regard, the internet page at the following link can be consulted: https://www.sail-world.com/Europe/Volvo-Ocean-Race-First-look-around-the-Super-60/-157014?source=google

[0021] In the light of the above considerations, there is a need to adopt a monohull type solution, which can sail in the planing condition even in offshore conditions in a stable manner and which can achieve and maintain optimal cruising conditions in the planing condition (e.g., a maximum speed condition and/or a desired height of the hull relative to the free surface of the sea) to be high performing during a sailing competition. In particular, there is a need to provide an adjustment mode which is effective and readily achieves a desired navigation condition.

[0022] The object of the invention is therefore to meet the above needs, preferably in a simple and/or effective and/or economical way in terms of energy expenditure.

SUMMARY OF THE INVENTION

[0023] Said object is achieved by means of a monohull sailing boat as defined in claim 1.

[0024] The dependent claims define particular embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] Hereinbelow, for a better understanding of the present invention, preferred embodiments will be described by way of non-limiting example, with reference to the attached drawings, wherein:

- Figure 1 is a simplified perspective view, with schematized parts, relating to a preferred embodiment of the monohull sailing boat of the present invention;
- Figure 2 shows the sailing boat of the present invention from the front, with a schematic indication of some forces the boat is subjected to during navigation under the so-called "planing condition".

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

[0026] In Figure 1, reference number 1 indicates, as a whole, a monohull sailing boat, illustrated partially and with schematized parts.

[0027] The boat 1 comprises a hull 2, which extends along a longitudinal axis 3, between a forward end or bow, as indicated by the reference 4, and a rear end or stern, as indicated by the reference 5. The boat 1 further comprises a set of sails 6 supported in a known manner, not described in detail, by masts protruding upwards from the hull 2.

[0028] The boat 1 is equipped with hydrodynamic load-bearing wings, referred to below as "hydrofoils", or more simply "foils", and configured to provide hydrodynamic lift as a result of the relative speed with respect to the water in which they are immersed. In particular, as will be better described below, the hydrodynamic lift of at least some of the foils is able to balance the weight of the boat 1 and thus achieve a navigation condition in which the hull 2 is substantially out of the water, if the wind intensity is such as to sail at relatively high speeds above a certain threshold (usually referred to as the "planing threshold"). The term "substantially" has been used above in relation to the position of the hull out of the water, as sea waves of a certain size can still lap the hull 2 during this navigation condition. The latter is shown schematically in Figure 2 and is usually referred to as the "planing condition", as mentioned above.

[0029] In greater detail, the boat 1 comprises two side arms 10, which are respectively arranged at opposite sides 11 of the hull 2 and are provided with respective foils 12. The outline shown in the attached figures for the foils 12 is to be considered as a non-limiting embodiment (e.g., the shape could also be straight, T-shaped, Y-shaped, etc.).

[0030] The arms 10 are connected to the hull 2 by a coupling system 13 (well-known and shown schematically) such that they are movable relative to the hull 2 between a deployed or lowered position (on the left in Figure 2), where the arms 10 protrude from the sides 11 such that they are spaced from the hull 2 and immerse their foil 12 in the water, and a retracted or raised position (on the right in Figure 2), where the arms 10 are close to, inside or above the hull 2, to keep their foil 12 out of the water.

[0031] The shifting between the retracted position and the deployed position is achieved by controlling a movement device 14 (shown schematically) which comprises, for each arm 10, a respective actuator 15. The actuators 15 are distinct and controlled separately from each other, in order to raise/lower the arms 10 independently of each other, and may be of the linear or rotary type. In addition, the movement device 14 can comprise a transmission between the actuators 15 and the respective arms 10.

[0032] The type of the coupling system 13 and the movement device 14 is not essential for the present invention. For example, the coupling system 13 can be of the hinge type to rotate the arms 10 between the retracted and deployed positions, or it can comprise a guide to translate the arms 10 between these positions, or it can be configured to provide the arms 10 with both a rotational motion and a translational motion. Furthermore, the coupling system 13 and/or the movement device 14 can be selected/designed so that the arms 10 can be selectively only positioned in the deployed and retracted positions, or they can be selected/designed so that the arms 10 can also be positioned in intermediate positions (not shown), to actively adjust the distance of the foils 12 from the sides 11 and thus the sinking of the same foils 12 in the water. The sinking adjustment can be used to vary the part of the foil 12 that remains submerged in the water and the part that remains out of the water, in order to adjust the hydrodynamic lift of the foil 12 itself (for example to adjust the height, or "heave", of the hull 2 in relation to the free surface of the water); and/or in order to vary the lever arm in relation to the centre of gravity CG (Figure 2) of the boat 1.

[0033] With reference to Figure 1, as an alternative or in combination with this possible adjustment of the arms 10, the lift of each foil 12 can be actively adjusted by means of a respective actuator 18, of the linear or rotary type, shown schematically and preferably powered by electrical energy. Each actuator 18 is connected to the respective foil 12 such as to vary an inclination and/or the shape of the outer profile of the foil 12, when it is operated. The two actuators 18 are distinct and controlled separately from each other, so that the lift of the two foils 12 can be adjusted independently.

[0034] In the specific example shown, each foil 12 has a front portion or attachment portion 19, fixed with respect to the arm 10, and a rear portion or outlet portion 20, rotatable with respect to the portion 19 about an axis 21 transverse to the axis 3: the actuator 18 thus acts on the inclination of the portion 20. However, the lift of the foils 12 can be actively adjusted by the actuators 18 in ways other than this specific example, as mentioned above.

[0035] Still referring to Figure 1, the boat 1 comprises a centreboard or keel 23, which projects downwards along an axis 24 from a portion 25 of the hull 2, which is arranged in an intermediate position between the bow 4 and the stern 5, and centrally between the sides 11. In particular, the portion 25 is the lowest part of the hull 2. Preferably, the axis 24 is orthogonal to the axis 3. More preferably, the keel 23 has a lower end supporting or defining a bulb 26, having a mass (for example approximately 30% of the vessel) such as to arrange the centre of gravity CG in a relatively low position and allow self-righting of the boat 1 even in the event of a total capsize.

[0036] In addition, preferably, along the longitudinal axis 3, the keel 23 is placed around the same longitudinal position as the centre of gravity of the hull 2 and the aerodynamic centre AC of the sails 6.

[0037] In the preferred embodiment shown, the portion 25 has a single keel 23 (in particular, to limit the hydrodynamic resistance, commonly called "drag").

[0038] According to one aspect of the present invention, the keel 23 supports at least one foil 28, which projects along an axis 29 transverse to the axis 24. In particular, the keel 23 supports two foils 28, which are arranged on opposite sides. In the specific example shown in Figure 1, the axes 29 along which the foils 28 extend are straight and orthogonal to the axis 24 (so as to substantially define an inverted T-shape, together with the keel 23). According to some variants, not shown, the axes 29 could form an angle other than 90° with respect to the axis 24 (for example defining a Y shape, or an inverted Y-shape), and/or the foils 28 could have a curved shape rather than a straight one.

[0039] In the preferred example shown, the foils 28 are arranged at the lower end of the keel 23. According to a variant, not shown, they are arranged in an intermediate position along the axis 24, e.g., approximately halfway along the keel 23. The foils 28 have such an extension that they protrude laterally with respect to the bulb 26.

[0040] In the preferred embodiment shown, the centre of gravity of the bulb 26 is positioned longitudinally forward of the point of application of the hydrodynamic force (F2 in Figure 2) exerted by the foils 28. In principle, however, configurations other than the preferred one shown here should not be excluded.

[0041] The lift of each foil 28 is established at the design stage so that it can support a substantial part of the weight of the boat 1, and more specifically at least the weight of the bulb 26 (approximately 10 tons, for example), and can be actively adjusted by means of a respective actuator 30, of the linear or rotary type, shown schematically and preferably powered by electrical energy. In other words, each actuator 30 is connected to the respective foil 28 such as to vary the inclination relative to the keel 23 (about an axis which substantially coincides with the axis 29) and/or the shape of the outer profile of the foil 28, when it is operated. Preferably, the two actuators 30 are distinct and controlled separately from each other, so that the lift of the two foils 28 can be adjusted independently.

[0042] This splitting allows the total hydrodynamic force (F2 in Figure 2) to be directed along a direction other than the axis 24. In addition, a negative lift can be set on each foil 28, i.e., a lift that is directed downwards, i.e. in the opposite direction to the hull 2.

[0043] Alternatively, a single foil 28 can be provided (and/or a single actuator 30 can be provided to adjust the lift of the two foils 28 jointly).

[0044] In the specific example shown, each foil 28 has a front portion or attachment portion 33, which is fixed with respect to the keel 23 (and the bulb 26), and a rear portion or outlet portion 34, also called "flap", which can be rotated with respect to the portion 33 about an axis which substantially coincides with the axis 29: the actuator 30 thus acts on the inclination of the portion 34. However, the lift of the foils 28 can also be adjusted in other ways, as mentioned above.

[0045] Preferably, the bulb 26 supports the foils 28 and/or houses the actuators 30.

[0046] According to a preferred aspect of the present invention, a portion of the keel 23 or the entire keel 23 is configurable to define a foil 35 having a hydrodynamic lift, which is also established at the design stage in relation to the weight of the boat 1 and can be actively adjusted by means of an actuator 36, of the linear or rotary type (shown schematically), preferably powered by electrical energy. For example, the actuator 36 is arranged and/or coupled in such a way that the inclination of the entire keel 23, or a portion thereof (e.g., a rear portion 37, called "flap"), is varied about the axis 24 and/or in such a way that the shape of the outer profile of the keel 23 is varied, when it is operated.

[0047] Preferably, with reference to Figure 2, the upper end of the keel 23 is coupled to the hull 2 so that it can rotate about an axis 40 substantially parallel to the axis 3, under the action of a linear or rotary actuator 41, e.g., powered by electrical energy. This type of rotation is referred to as "cant". In this way, with respect to a central reference direction 27 that is vertical in static rest conditions, the bulb 26 and, therefore, the centre of gravity CG of the boat 1 can be moved laterally, to the right or the left. Similarly, the points of application of the forces F2 and F3 due to the hydrodynamic lift of the foils 28 and 35 are moved to the right or the left. Therefore, both the lever arm with respect to the centre of gravity CG and the direction of the force vectors are varied in order to adjust the torque exerted by the foils 28 and 35 and thus the righting torque with regard to the roll balance. The rotation of the bulb 26 with respect to direction 27 also assists the self-righting of the boat 1 in the event of total or partial capsizing, regardless of its forward speed.

[0048] In particular, the axis 24 of the keel 23 can rotate by a maximum angle of approximately 35°-40° about the axis 40 from the reference direction 27.

[0049] Going back to Figure 1, the boat 1 further comprises a rudder 44, which projects downwards from the hull 2 at the stern 5, in a central position between the sides 11 and, in use, is rotated (operated manually and/or by an actuator, not shown) about a steering axis 45 substantially parallel to the reference direction 27, to steer the boat 1 during navigation, i.e., to set a yaw torque.

[0050] In addition, at a lower end of the rudder 44, the boat 1 comprises at least one foil 46, commonly referred to as an elevator and having a hydrodynamic lift which can be actively adjusted by means of an actuator 47 (shown schematically), of the rotary or linear type, preferably powered by electrical energy, in order to define a pitch torque and then set the pitch angle. This hydrodynamic lift is adjusted by varying the inclination of the entire foil 46, or a portion thereof, in particular the rear portion (also called "flap"), about an axis 49 that is orthogonal to the axis 45. In particular, the front part of the foil 46 and the rudder 44 are part of a single rigid body.

[0051] Figure 2 shows, in a simplified way, the main forces the boat 1 is subjected to during navigation, when the boat 1 is in the planing condition. The arms 10 are positioned by the movement device 14 so that one of the two (i.e., the upwind one) is in the raised position and the other (the downwind one) is in the lowered, or at least partially lowered, position, so as to immerse, at least partially, the corresponding foil 12 in the water.

[0052] The boat 1 is therefore supported by at least three points, defined by the foil 12 arranged downwind, by the foils 28 carried transversely by the keel 23, and by the foil 47 associated with the rudder 44, respectively.

[0053] Preferably, in combination with the support point defined by the foils 28, there is the support point defined by the foil 35, which is directly provided on the keel 23, in particular if the latter is tilted with respect to direction 27. Therefore, the keel 23 supports both the foils 28 and the foil 35, so it actually has more active support surfaces in the water in the planing condition.

[0054] In particular, the rest on the two points defined by the foil 12, which is immersed in the water, and the foils 28 (with the possible addition of the foil 35) ensures roll balance. The rest on the two points defined by the foils 28 (with the possible addition of the foil 35) and the foil 46, on the other hand, ensures pitch balance.

[0055] Figure 2 considers the forces at stake with regard to the roll balance. The hydrodynamic lift of the foil 12 arranged downwind defines a hydrodynamic force F1, which can be broken down into a vertical component F1v and a horizontal component F1o. As regards the other foil 12 which remains out of the water, its aerodynamic lift can be neglected (although, in some configurations, the position of its weight with respect to the hull 2 may be relevant to generate a torque).

[0056] The foils 28 and 35, in turn, offer a hydrodynamic force F2 (broken down into a vertical component F2v and a horizontal component F2o) and a hydrodynamic force F3, respectively (broken down into a vertical component F3v and a horizontal component F3o).

[0057] At the same time, the wind exerts a lateral thrust F4 on the aerodynamic centre AC of the sails 6. In this regard, the vertical wind force component on the sails can be neglected for relatively small heel angles.

[0058] Finally, the weight force of the boat 1, acting on the centre of gravity CG, is indicated by the reference P.

[0059] Under balanced conditions, the sum of the vertical components F1v, F2v and F3v and the weight force P must cancel out. The vertical components F1v, F2v and F3v of the hydrodynamic lift of the foils act on the height of the hull 2 in relation to the free surface of the water (this height is usually indicated by the term "heave").

[0060] At the same time, in order to achieve roll balance, the sum of the torques or moments generated by the forces F1, F2, F3 and F4 around the centre of gravity CG must cancel out (in other words, the heeling moment generated by the force F4 of the wind must be balanced to prevent capsizing and/or to maintain a given heel angle with respect to the vertical.)

[0061] In addition, in order to control the leeway phenomenon, the sum of the horizontal components F1o, F2o, F3o and F4 should cancel out or have a desired value. For example, the hydrodynamic lift of the foil 35 can be adjusted to take advantage of the lateral component F3o to compensate for the lateral force F4 of the wind.

[0062] First of all, it is immediately noted that the balance of forces and the balance of torques are stable in themselves (and not unstable as in the AC75 class yachts), since the boat 1 is supported, in relation to the roll, by the hydrodynamic action of the water in at least two points which, generally, are arranged in a horizontal direction on opposite sides of the aerodynamic centre AC, i.e. in a first point defined by the foil 12 which is immersed in the water and in at least a second point defined by the foils 28 carried transversely by the keel 23.

[0063] In greater detail, under balanced conditions, the weight force P is compensated not only by the vertical component F1v of the foil 12 which is immersed in the water (as in the AC75 class yachts), but also by the vertical component F2v of the foils 28 (and possibly also by the component F3v of the foil 35): in other words, the downward vertical load of the boat 1 is divided between the foil 12 and the foils 28 (and possibly also foil 35). In this regard, the vertical load supported by the foil 46 is neglected.

[0064] Preferably, as mentioned above, the foils 28 and 35 are set via the respective actuators so as to all contribute to the balancing.

[0065] In the planing condition, when the boat 1 is disturbed by external factors (wind, wave motion, etc.), the boat 1 itself is able to compensate for these disturbances passively (i.e. without acting on the actuators) and thus find a new balance situation on its own, albeit at the expense of a temporary drop in performance. This automatic and passive compensation is mainly due to the fact that the water-immersed part of the foils 12, 28 and 35 varies when there is a change in the previous balance situation. In fact, in case of imbalance, the foils tend to change their position in relation to the free surface of the water and therefore submerge more or less, compared to the previous balanced situation: foils that submerge more increase their water-immersed surface and therefore their hydrodynamic lift increases, so that the hydrodynamic resistance consequently increases to the detriment of the speed which is reduced; on the contrary, foils that rise and come out of the water more decrease their hydrodynamic lift due to a smaller submerged surface, so the hydrodynamic resistance consequently decreases in favour of the speed which increases; these submersion changes end when the loads are rebalanced.

[0066] As is apparent from Figure 2 and as mentioned above, this passive automatic compensation also concerns the foil 28 which is arranged upwind, due to the upwind inclination of the keel 23 (i.e., in the opposite direction to the side arm 10 which is arranged downwind and is lowered) with respect to direction 27. In this respect, the foils 28 should be designed to have a relatively large dimension along the axis 29.

[0067] To speed up the stabilization process leading to the new balance situation, and thus improve the performance of the boat 1, the hydrodynamic lift of the foils is actively adjusted by operating the actuators described above (or at least some of them) in a coordinated manner.

[0068] In this respect, the force F4 can be estimated, but with a potential error, so the active adjustment of the lift of the foils must be based on the position and orientation angles of the hull 2 (i.e., the roll, pitch, and yaw angles), on the distance of the hull 2 from the free surface of the water, on the speed and direction of the wind, on the speed of the hull 2 relative to the water, etc. This set of quantities is commonly referred to as the "state". In this regard, the boat 1 comprises appropriate sensors to provide this information, as will be described in detail below.

[0069] As a possible example of active adjustment, for the sake of simplicity we neglect the possible lift of the foil 35 and the possible rotation of the keel 23 about the axis 40 (so that the axis 24 of the keel 23 coincides with the reference direction 27) and we assume a roll balance condition in which the heeling moment is balanced entirely by the hydrodynamic lift of the foil 12 immersed in the water. In the event of changes in wind conditions, the actuators 18 and 30 can be controlled to adjust the hydrodynamic lift of the foils 12 and 28 in a coordinated and simultaneous manner to compensate for these changes, without necessarily acting on the sails 6 or the actuators 15. In fact, for example, if a wind drop is assumed, and therefore a decrease in the lateral force F4 of the wind, resulting in a decrease in the heeling moment, the righting torque must be reduced to maintain the balance: in this regard, the hydrodynamic lift of the water-immersed foil 12 can be reduced by means of the actuator 18; this reduction in the force F1 would lead to unbalancing the weight P, but to prevent this, the lift of the foil 28 is also adjusted at the same time by means of the actuator 30 (i.e., by increasing the force F2, correspondingly), without substantially affecting the righting moment, given that the force F2 is directed along the axis 24 and therefore towards the centre of gravity CG, in the simplified hypothesis taken into consideration.

[0070] More generally, it is also possible to act on the amount of lift of the foil 35 via the actuator 36, and/or on the points of application of the forces F2 and F3 (and on the position of the centre of gravity CG) by rotating the keel 23 via the actuator 41.

[0071] It is therefore clear that these possible adjustments on the lift of the various foils allow for many degrees of freedom compared to the prior art, to respond to disturbances and actively balance the boat 1 in a relatively fast and precise way.

[0072] Therefore, given the number of control variables available in the adjustments, it is also possible to find multiple possible lift settings to be assigned to the different foils in order to achieve vertical balance (i.e., to balance the weight P), rotational balance (roll and pitch balance), and the optional balance of the lateral components (to control the leeway). In other words, the system is overactuated.

[0073] Thus, within certain limits, the actuators 15, 18, 30, 41 and 47 can be controlled to distribute the vertical load as desired among the foils 12, 28, 35 and 46, so as to set hydrodynamic lifts which support respective load shares and still maintain rotational balance (roll and pitch balance).

[0074] For example, prominence can be given either to a vertical thrust close to the centre of gravity CG, via the foils 28, or to a vertical thrust in a lateral position, via the foil 12.

[0075] The selection of the load distribution shares among the various foils and/or the selection of which foils to actually adjust are carried out according to specific external conditions (wind intensity and direction, wave conditions, the possible presence of a storm, etc.) and/or according to a certain requirement during the planing condition: for example, maintaining the roll angle around the axis 3 within a given range; minimizing energy consumption; minimizing hydrodynamic resistance; reaching a speed setpoint; maximizing the VMG (Velocity Made Good), that is, the speed to approach the target; reaching a height setpoint, or keeping the hull 2 above a minimum height, in relation to the free surface of the water; minimizing energy consumption when operating the actuators; or a combination or set of at least some of these possible options.

[0076] In other words, in addition to balancing forces and torques, in the planing condition the actuators 15, 18, 30, 41 and 47 are advantageously controlled in a coordinated manner to achieve and maintain a desired operating condition. The latter is generally referred to as the target state.

[0077] As a simplified example, a desired height from the free surface of the water can be achieved by operating at least some of the actuators (15, 18, 30, 36, 41, 47) : if the detected height is greater than the desired height, the overall vertical component generated by the lift of the foils is temporarily reduced (i.e., the sum of the vertical components F1v, F2v and F3v is temporarily reduced) to generate an imbalance that causes the boat 1 to be lowered to the desired height, and then the vertical balance is restored to achieve a new point of balance. This adjustment to the forces F1, F2 and F3, to lower (or raise) the boat 1 in the planing condition is carried out in such a way that the balance of the roll and pitch torques is maintained at all times. Preferably, the balance of the lateral components of the forces is also maintained.

[0078] In particular, by adjusting the lift of the foils, it is possible to maximize the VMG in the planing condition, even if indirectly, i.e., by acting on other parameters.

[0079] In principle, the controls for the coordinated operation of the actuators 15, 18, 30, 36, 41, 47 can be performed/set manually. However, since there are many adjustable foils, and in some cases they act on several parameters of the boat 1 (e.g., pitch angle, roll angle, vertical lift, etc.) at the same time, the selections relating to which actuators are actually to be operated and how many commands are to be imposed in order to obtain the target state are very complex. Therefore, according to a preferred aspect of the present invention, at least some of the actuators 15, 18, 30, 36, 41, 47 are controlled automatically by an electronic control and processing unit, schematically shown and indicated by the reference 50 in Figure 1. Preferably, the electronic unit 50 is configured with a control strategy which adjusts the configuration of the foils in a closed-loop manner during navigation.

[0080] Preferably, a user interface (not shown) is provided, so as to be able to select or set the desired operating condition to be achieved. In other words, the skipper can set the desired operating condition according to the external conditions present during navigation, and is also preferably enabled to set one or more restrictions on the parameters managed by the electronic unit 50; the latter will then determine what is the optimal solution for adjusting the foils to achieve the target state, and to respect the restrictions, which have been set by the skipper.

[0081] As mentioned above, the electronic unit 50 is connected to a set of sensors and is configured to process the information provided by these sensors and then automatically control the actuators (or valves that then operate the actuators) in order to achieve the balance of the boat 1 and the desired operating condition.

[0082] The aforementioned sensors comprise at least one inertial system, which is schematically shown and indicated by the reference 51 in Figure 1, to obtain information relating to spatial orientation (pitch, roll and yaw angles), absolute position, speed and accelerations of the hull 2, and comprises sensor elements of a type known per se, such as GPS, IMU, gyroscopes, accelerometers, magnetometers, etc. In particular, the boat 1 comprises a multitude of these sensor elements, arranged at different points, to provide redundant information and/or information relating to specific positions and components of the boat 1.

[0083] With the information provided by the system 51, it is possible to determine the position at sea, the direction of navigation, the various components of the speed of the boat 1, any pitch and/or roll oscillatory phenomena, etc. By way of example, by comparing the lateral component of the absolute speed of the boat 1 with the spatial orientation of the longitudinal axis 3, it is possible to determine the leeway of the boat 1 during navigation. It is also possible to determine any deviation from the maximum VMG in a given condition (for example, in order to minimize this deviation, in the processing performed by the electronic unit 50).

[0084] Preferably, the above-mentioned sensors also comprise a distance detection system, for example with ultrasonic detection, schematically shown and indicated by the reference 52 in Figure 1, of a type known per se, aimed in such a way as to determine the distance of the hull 2 from the free surface of the water. More preferably, the system 52 is arranged at the bow 4, so that data on the free surface of the water can be obtained sufficiently in advance; the electronic unit 50 is then equipped with appropriate strategies to eliminate any disturbances and filter the sea wave data appropriately.

[0085] In addition, the electronic unit 50 preferably receives information output by the sensors (of a type known per se, not shown) which detect the intensity and/or direction of the wind (i.e. the apparent conditions of the wind relative to the boat 1) and/ or the speed of the hull 2 relative to the water (therefore also taking sea currents into consideration).

[0086] Preferably, the electronic unit 50 is configured by means of a control strategy that achieves the desired operating condition via a model of the dynamic behaviour and balance of the boat 1, based on a MIMO (Multiple Inputs Multiple Outputs) type system. The term "inputs" generally refers to observable quantities (which comprise at least part of the signals provided by the aforementioned sensors or are quantities that can be directly derived from these signals). By contrast, the term "outputs" refers to controllable quantities, which allow the control signals to be output to operate the actuators 15, 18, 30, 36, 41, 47 to be determined by means of pre-established functions or correlations.

[0087] At the same time, the model may contain one or more restrictions, indicative of physical restrictions that must not be exceeded, for example, a maximum threshold of distance of the hull 2 from the free surface of the water (to keep the foils immersed in the water), a maximum roll angle threshold, a maximum range of travel for each foil during its adjustment, a maximum adjustment speed for each foil, etc.

[0088] Furthermore, the control strategy preferably comprises an optimisation function to be maximised or minimised, i.e. optimised. In other words, optimisation is the determination of values of unknown variable quantities that minimise or maximise the optimisation function, respectively. Optimisation may be subject to one or more restrictions: for example, as generally known in optimal control theory, the restrictions may be included as factors of the optimisation function via the Lagrange multiplier method. In particular, the optimisation function is a cost function to be minimised.

[0089] According to a preferred embodiment, the cost function is set to minimise the energy consumption required to operate the actuators.

[0090] Preferably, the dynamics model of the boat 1 is used to determine the target state, in response to the user settings in the aforementioned interface and in response to detected disturbances (wind, waves), i.e., in response to the detections performed by the above-mentioned sensors.

[0091] The control strategy further comprises a - state observer, which receives the sensor readings as input. The target state determined by the model is compared by a controller with the observed state generated by the state observer. The controller is configured in such a way that the difference between the two states (target and observed) is eliminated by using the cost function, which is minimised, in order to identify the unknown controllable quantities. The latter, preferably, are defined by the hydrodynamic forces to be obtained for the various foils of the boat 1.

[0092] For the sake of clarity, the term "difference" (between the target and the observed state) is here understood broadly, so as to encompass any kind of distinction; therefore, the difference is not understood to be limited to a subtraction only, but could also be represented by a ratio, a standard deviation, and the like.

[0093] Starting from the hydrodynamic forces that have been identified by minimising the cost function, the electronic unit 50 is then configured to determine the displacements/positions to be assigned to the respective foils by the actuators. In this regard, the electronic unit 50 has a memory containing a pre-established correlation between forces and displacements, for each foil: in particular, this correlation is obtained by means of a representative model of each foil (for example, a model in terms of lift coefficient and drag coefficient, known per se to those skilled in the art).

[0094] Finally, the electronic unit 50 is configured in such a way that the displacements/positions, which have been previously identified, are converted into respective control signals to be output to actually operate the actuators (15, 18, 30, 36, 41, 47) and then set the lift of the various foils.

[0095] Finally, the implemented strategy also allows a closed-loop control to be performed, by estimating a future state ahead of time and, after that time has elapsed, by comparing the previously estimated state with the actually observed state to determine a deviation for the closed-loop control.

[0096] The advantages of the boat 1 according to the invention are clear from the foregoing.

[0097] In practice, the existing types of boats do not have the characteristics to achieve the aim of high average speed in all conditions and in particular in adverse weather conditions. Specifically, this is due to the inability to maintain the foils in the water with high wave motion and/or the inability of the boats to react to sudden wind increases in a dynamic manner.

[0098] The boat 1 achieves the advantages through the increase in mass, and consequently inertia and righting moment, due to the presence of the bulb 26 in upwind sailing/beating, where the ability to counteract wind heeling goes hand in hand with the power that can be achieved by the boat 1. It is still able to keep planing due to the immersion of the foils 28 well below the free surface.

[0099] On the other hand, in downwind sailing where the wind is more aligned with the direction of motion, and therefore the righting moment is not so critical, the excess weight of the bulb 26 is supported by the foils 28 thus leaving the foils 12 to manage a small part of mass and the dynamic stability.

[0100] The boat 1 has a relatively low aerodynamic resistance, as it is of the monohull type, and also a low hydrodynamic resistance, as it can easily sail in the planing condition thanks to the lift exerted by the foils 28 which are carried transversely by the keel 23. In particular, the foils 28 allow the boat 1 to be brought into the planing condition even for speeds lower than those of the well-known sailing boats.

[0101] Furthermore, by setting the lift of the foils 28 to the maximum value, it is possible to facilitate the transition from the displacement condition to the planing condition, i.e. to facilitate the exit of the hull 2 from the water. In particular, this transition is made with the axis 24 of the keel 23 arranged along the reference direction 27 (the keel 23 is tilted to the right or the left about the axis 40 only after achieving the planing condition).

[0102] The combined use of the foil 28 and the upwind inclination of the keel 23 with respect to direction 27 is particularly advantageous: this inclination allows a lateral end of the foil 28 to emerge from the water upwind, in the planing condition, in order to achieve a passive automatic rebalancing of the hull 2, which is more effective than the known solutions.

[0103] It is also clear that the use of two separate and independently operated foils 28 makes the proposed solution even more versatile.

[0104] Furthermore, as explained above, in the planing condition, the hull 2 is supported by the water in at least three points, so it has a stable balance, which can be restored relatively easily in the event of external disturbances, without necessarily having to act on the sails. For this purpose, the actuators for adjusting the lift of the foils are controlled separately, and in a coordinated manner, to achieve the balance situation.

[0105] Furthermore, the presence of the bulb 26 and the rotation about the axis 40 allow the boat 1 to be self-righting in the event of a partial capsize and in the event of a total capsize.

[0106] Furthermore, as explained above, the adjustment system is automatic, due to the presence of the electronic unit 50 that operates in response to the sensor signals, so the adjustment is timely, precise and reliable.

[0107] Moreover, optimal settings can be found to achieve a desired operating condition, such as maximising the VMG, and not just maintaining a stable balance, in the planing condition. In addition, the control system is extremely flexible, due to the number of control variables on which the electronic unit 50 can act to achieve the balancing and desired operating conditions in the planing condition.

[0108] Furthermore, the control logics used, described above as a preferred embodiment, are effective in achieving optimum and precise control, with low response times.

[0109] Other advantages are also apparent to those skilled in the art on the basis of the detailed description of the preferred embodiments set out above.

[0110] Lastly, it is clear that modifications and variations may be made to the boat 1 according to the above description without however departing from the scope of protection defined by the appended claims.

[0111] In particular, as mentioned above, the shape, size, orientation, and position of the foils 12, 28, 35, 46 may differ from what is schematically indicated by way of example in the attached figures.

[0112] In addition, the control strategies implemented in the electronic unit 50 (for example the dynamic model of the boat) may be subject to possible modifications and/or further studies and/or experiments to improve what is set out above by way of example.

Claims

1. A monohull sailing boat (1) comprising:

- a hull (2) having a bow (4), a stern (5) and two sides (11) opposite each other, and extending along a longitudinal axis (3) from said stern to said bow;
- a pair of side arms (10), which are arranged at said sides (11), respectively, comprise, each, a respective first hydrofoil (12) and are movable relative to the respective said side (11) between a retracted position and an at least partially deployed position;
- actuator means (15) for moving said side arms (10) between said retracted position and said at least partially deployed position;
- a pair of first actuators (18) operable to respectively adjust the lift of said first hydrofoils (12);
- a rudder (44) arranged at the stern and pivoting about a steering axis (45);
- a second hydrofoil (46) arranged at said rudder (44);
- a second actuator (47) operable to adjust the lift of said second hydrofoil (46);
- a keel (23) projecting downwards from an intermediate portion (25) of said hull (2), between said stern and said bow;

characterized by further comprising:

- at least one third hydrofoil (28), which is carried by said keel (23) and projects transversally with respect to said keel (23); and
- a third actuator (30) operable to adjust the lift of said third hydrofoil (28).

2. The boat according to claim 1, wherein said keel (23) carries a pair of third hydrofoils (28) projecting transversally and in opposite directions with respect to said keel (23); a pair of third actuators (30) being provided for adjusting the lift, respectively, of said third hydrofoils (12) independently of each other.

3. The boat according to claim 1 or 2, wherein said keel (23) is rotatable with respect to said hull (2) about an adjustment axis (40) substantially - parallel to said longitudinal axis (3); and wherein the boat (1) further comprises a further actuator (41) for rotating said keel (23) about said adjustment axis (40).

4. The boat according to claim 3, wherein the boat (1) further comprises an electronic unit (50) configured to control said further actuator (41) and rotate upwind said keel (23) about said adjustment axis (40) when the side arm (10), which, in use, is arranged downwind, is in its at least partially deployed position, with its first hydrofoil (12) arranged at least partially in the water, after the hull (2) has achieved a planing condition in which it is arranged substantially out of the water due to the hydrodynamic lift of said hydrofoils (12,46,28).

5. The boat according to claim 3 or 4, wherein the boat (1) comprises:

- a fourth hydrofoil (35), which defines part of said keel (23); and
- a fourth actuator (36) operable to adjust the lift of said fourth hydrofoil (35).

6. The boat according to any one of the previous claims, wherein said keel (23) has a lower end supporting a bulb (26) .

7. The boat according to claim 6, wherein said third hydrofoil (28) is supported by said bulb (26).

8. The boat according to claim 7, wherein said third actuator (30) is housed in said bulb (26).

9. The boat according to any one of the previous claims, further comprising:

- a sensor system (51,52) configured to detect state information comprising, at least, the absolute position and orientation angles of said hull (2) and the distance of said hull from the water surface;
- an electronic unit (50) connected to said sensor system (51) to receive said information and configured so as to output control signals to operate said actuators in a coordinated manner in response to said information in order to achieve and/or maintain a balance of said hull (2), at least with respect to vertical force components (P) and with respect to roll and pitch rotations, when the boat (1) is sailing, in use, in a planing condition, in which the side arm (10) that is arranged downwind is in its at least partially deployed position, with its first hydrofoil (12) arranged at least partially in the water, and the hull (2) is arranged substantially out of the water due to the hydrodynamic lift of said hydrofoils (12,46,28).

10. The boat according to claim 9, wherein said electronic unit (50) is configured to output control signals such as to achieve a desired operating condition, in addition to said balance, when the boat (1) is sailing, in use, in said planing condition.

11. The boat according to claim 10, wherein said electronic unit (50) comprises a dynamic model of said boat (1) and an optimization function, and is configured to determine said control signals by maximizing

or minimizing said optimization function.

12. The boat according to claim 11, wherein said electronic unit (50) comprises a state observer for generating an observed state in response to said information, and is configured to:

- determine a target state based on said dynamic model,
- compare said observed state with said target state, and
- maximise or minimise said optimisation function to eliminate differences between said observed state and said target state.

13. The boat according to claim 12, wherein said electronic unit (50) is configured to:

- determine a respective hydrodynamic force to be obtained for each said hydrofoil, in response to maximising or minimising said optimisation function;
- determine a displacement or position to be assigned to each said hydrofoil by the respective actuators in response to said hydrodynamic forces and according to a predetermined model correlating, for each said hydrofoil, said displacements/positions to said hydrodynamic forces;
- determine said control signals in response to the previously determined displacements/positions.

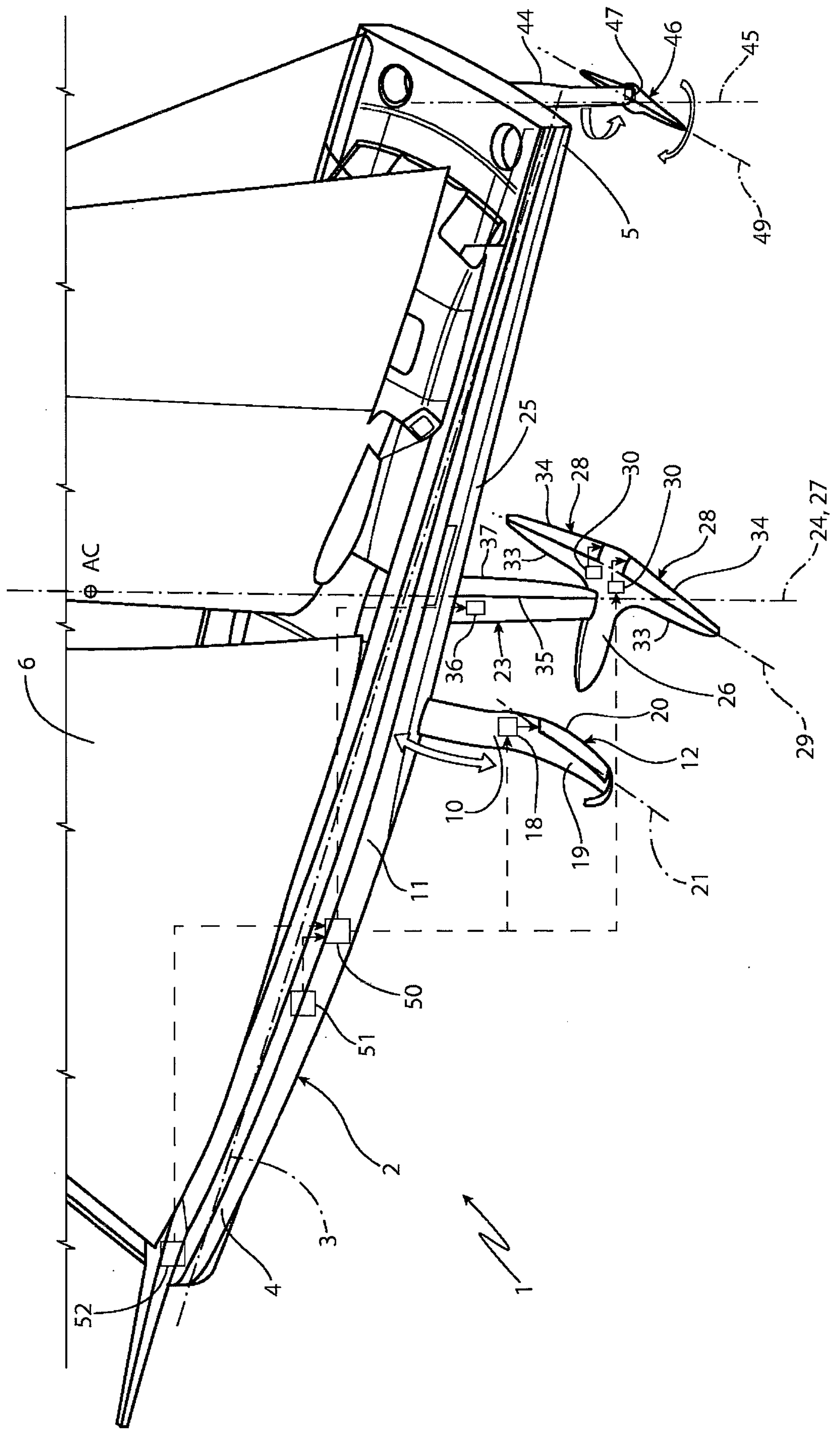

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FIG.1

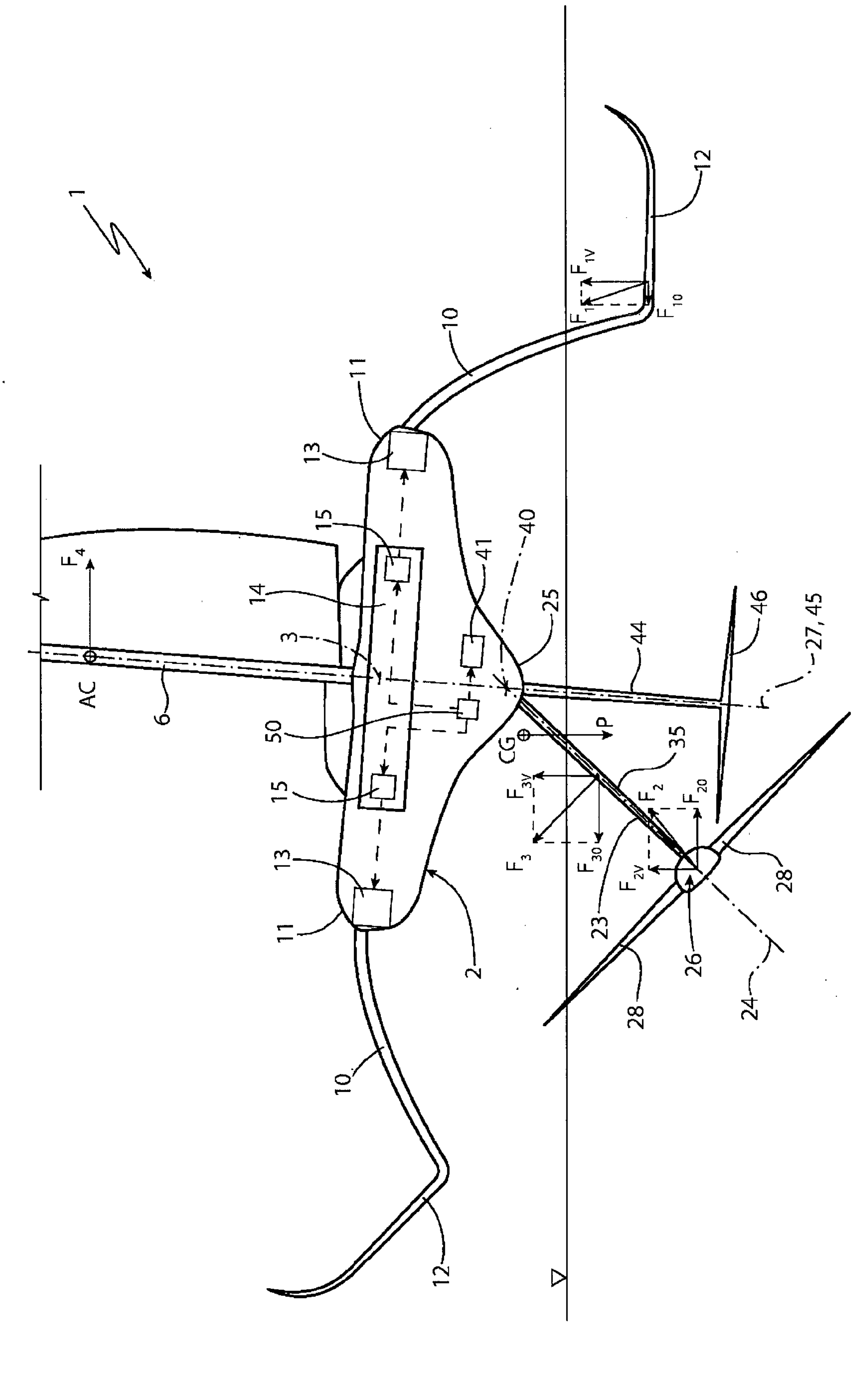
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FIG.2

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EUROPEAN SEARCH REPORT

Application Number
EP 24 31 5389

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	Unknown: "POGO FOILER Nouvelles sensations", , 20 June 2022 (2022-06-20), XP093140949, Retrieved from the Internet: URL:https://web.archive.org/web/20220720032551if_/https://www.pogostructures.com/wp-content/uploads/2021/01/POGO-foiler-Presentation.pdf [retrieved on 2024-03-13] * the whole document * -----	1-13	INV. B63B1/24 B63B1/26 B63B1/28 B63B1/30 B63B3/38 B63B35/00
A	WO 2023/047243 A1 (DEGENNARO DAVIDE [IT]) 30 March 2023 (2023-03-30) * figures * -----	1-13	
A	FR 3 130 738 A1 (FLY R [FR]) 23 June 2023 (2023-06-23) * figures 1-3 * -----	1-13	

TECHNICAL FIELDS SEARCHED (IPC)

B63B

The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
The Hague	23 January 2025	Schmitter, Thierry

CATEGORY OF CITED DOCUMENTS

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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 24 31 5389

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23-01-2025

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2023047243 A1	30-03-2023	EP 4405242 A1	31-07-2024
		WO 2023047243 A1	30-03-2023
FR 3130738 A1	23-06-2023	AU 2022419159 A1	18-07-2024
		EP 4452739 A1	30-10-2024
		FR 3130738 A1	23-06-2023
		WO 2023118210 A1	29-06-2023

EPO FORM P0459

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

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- IT 102023000017682 **[0001]**