Sept. 24, 1963 G. PIAZZA 3,104,642

CARRIER WING UNIT FOR A CRAFT WITH A CONSTANT PREDETERMINED LIFT, AND SELF-VARIABLE INCIDENCE

Filed Oct. 10, 1960 2 Sheets-Sheet 1

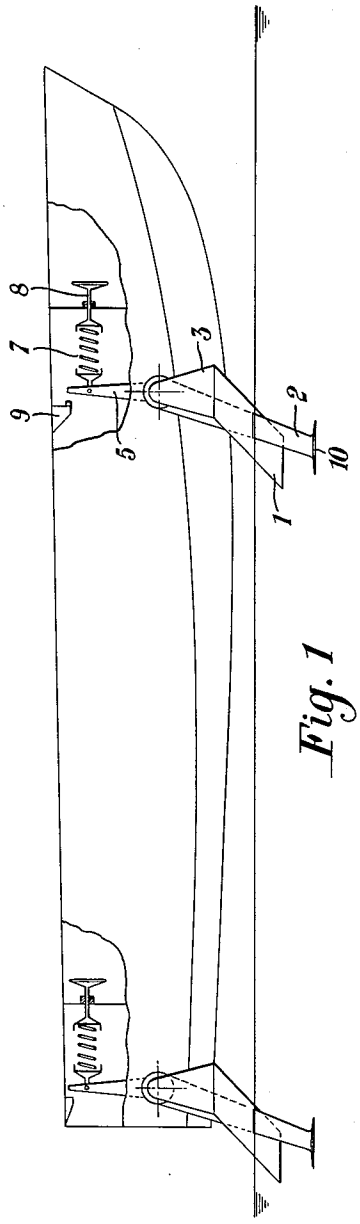

Fig. 1

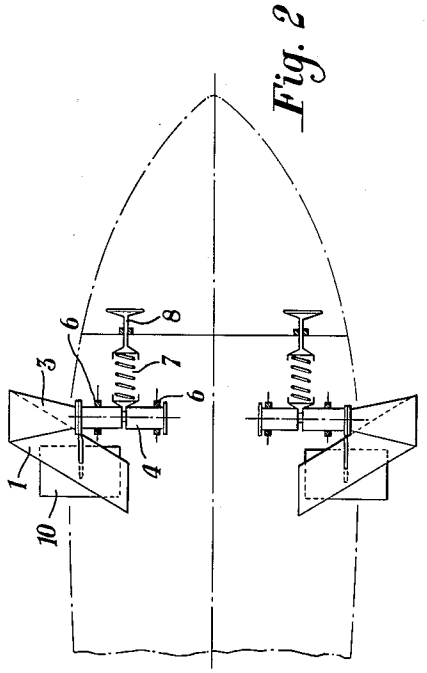

Fig. 2

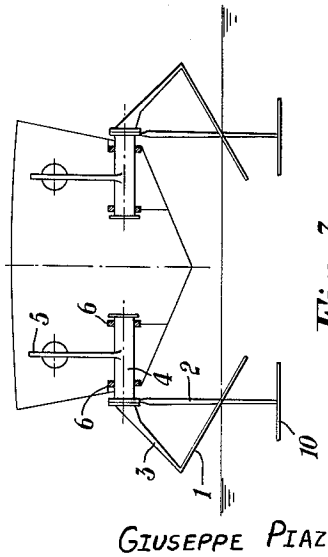

Fig. 3

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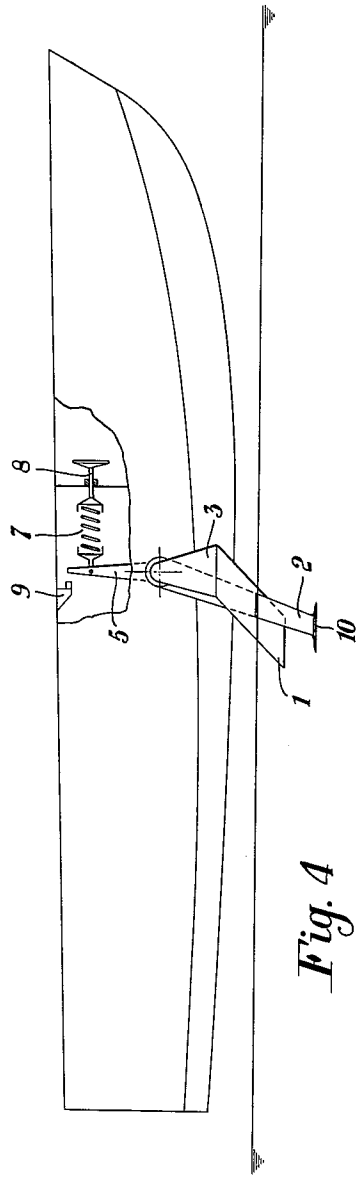

Fig. 4

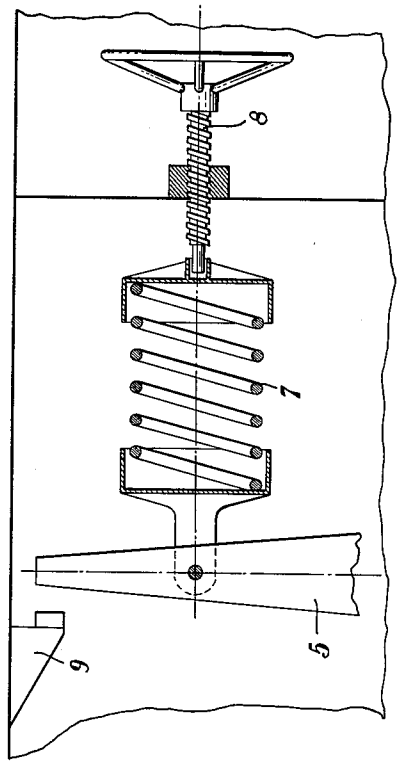

Fig. 5

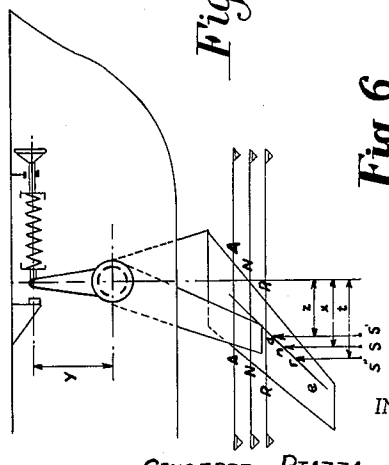

Fig 6

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CARRIER WING UNIT FOR A CRAFT WITH A CONSTANT PREDETERMINED LIFT, AND SELF-VARIABLE INCIDENCE

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6 Claims. (Cl. 114—66.5)

It is known that the carrier wings applied to a hydrofoil craft are for the purpose of lifting during the motion the hull out of the water to minimize the resistance to motion and to obtain greater speeds for a given power.

The lift of the wing system is mainly a function of the speed of the immersed wing surface and of the incidence angle of the wings.

The lifting wing systems applied to the crafts must mainly ensure:

The take off or raising of the hull from the water;

The level or height of navigation on the water level;

The trim and the longitudinal stability;

The transverse stability.

The lifting wing systems known up to now suffer certain disadvantages which are common to almost all of said systems, and said defects may be summarized as follows:

A change of the longitudinal trim causes a change of the wing incidence and therefore a variation of the lift;

The navigation in direction at right angles to the wave direction (head or following waves), due to the variation of level of the water and the orbital motion of the waves causes a variation of the lift, which increases or decreases due to both the variation of immersion of the lifting wing surface and to the specific unitary thrusts which are variable in relation to the aforesaid orbital movements.

The variation of lift of the fore wing unit of the craft is normally out of phase with respect to that of the stern wing unit.

The navigation in a direction parallel to the wave direction, in addition to the effect described above causes an oscillating variation of lift (increasing or decreasing it) putting out of phase the lift of the starboard wing unit with respect to that of the port wing unit.

The above discussed disadvantages in the practical application of such hydrofoil wings cause variations of height from the water level and pitching and rolling movements which are prejudicial to the safety of the navigation. In fact:

(*a*) Assuming that the fore wing is in a wave trough and the aft wing in a wave crest, the boat bow will go down and the boat stern will go up, the boat gets a bow heavy trim and therefore the incidence of the wings on the horizontal plane diminishes, and can also in certain cases reach a zero value—the lift of the wing system is thereby reduced or annulled—the boat will be lowered and the bow will strike against the crest of the subsequent wave tending to dive into it;

(*b*) Assuming that the fore wing is in a wave crest and the stern wing in a trough, the bow goes up and the stern is lowered; the boat assumes a stern heavy trim and therefore the incidence of the wings to the horizontal plane increases so that the total lift of the foil system goes up to almost double, the boat is raised and tends at the limit to "porpoise" out of the water with the consequent progressive reduction of the transverse stability and the consequent danger of heeling over:

(*c*) Assuming the boat to be running parallel to the wave formation (i.e. with the waves coming athwartship), at one side the wings will be more immersed than at the other side, and at this side the boat tends to raise, rotating about a longitudinal axis. The rolling oscillation thereby obtained is remarkably uncomfortable for the passengers of the boat and under particular synchronism of conditions between the natural oscillating period and the speed of the waves, the heeling angle tends to increase and sudden capsizing of the boat on the water can occur.

The present invention removes the above mentioned defects ensuring a safe movement over the water and the maximum comfort for the passengers.

The invention will now be described more particularly with reference to the accompanying drawings, in which:

FIG. 1 is a schematic side elevation view of a ship with wing units mounted on the bow and the stern of the ship;

FIG. 2 is a partial top plan view of the construction of FIG. 1;

FIG. 3 is a front elevation view of the construction of FIG. 1;

FIG. 4 is a schematic side elevation view of a ship with a single wing unit thereon;

FIG. 5 is a side elevation view, on an enlarged scale, and partly in section of the spring tensioning means for the embodiments of FIGS. 1 and 4; and

FIG. 6 is a diagrammatic view of a wing unit with the forces and moment arms shown thereon.

The present invention comprises arranging the wing units as hereinbelow described. In FIGS. 1, 2 and 3 the wing **1** is secured to a first arm **2** near the middle of its length and to a transverse fin **3** at one end thereof. The arm **2** and fin **3** have the other ends thereof secured to an axle **4**. On the axle **4** is secured a second arm **5**. The axle **4** is supported in conventional journal bearings **6** secured to the hull. On the bottom of the arm **2** is a second wing **10** which extends horizontally. The assembly of the parts **1**, **2**, **3**, **4**, **5** and **10** can thus effect rotational oscillations in the bearing **6**. In the FIGS. 1 and 3 the bow of the ship is on the right hand end of the figure and the craft moves from the left to the right. With reference to the ship, the wing **1** extends outwardly, upwardly and forwardly, with the end connected to fin **3** the foremost end, so that the line of application of the total thrust lies abaft the axis of rotation through axle **4**. The torque produced by the thrust is balanced by the torque produced by a spring **7** which acts on the end of the arm **5**.

The adjustment of the compression of the spring **7** can be produced by means of a load adjusting system comprising screw **8**, the detail of which is shown, on a larger scale in FIG. 5.

The spring **7** and the load adjusting screw **8** have been mentioned by way of example, and other conventional means can be employed, such as a mechanical-hydraulic system, mechanical-pneumatic system, a hydro-pneumatic system or other suitable system. In order to limit the movement of arm **5** when the hull is in a stationary condition and when the ship is just starting, a stop **9** can be

positioned in a suitable position. Said stop thus limits the maximum incidence angle of the wing.

In the above described wing unit there are combined in a single complex concept three elementary features: first the possibility of wing rotation so as to obtain a change of the incidence angle automatically; secondly, the arrangement of the wing which extends outwardly, upwardly, and forwardly relative to the hull so that the thrust center or, more exactly, the evolute of the thrust centers moves away from and abaft as the hull rises and the draft of the wings decreases; and thirdly that the spring, or other suitable system causes, for any rotational displacement of the wing, a change of the reactive moment higher than the variation of the active moment produced by the action of lift on the wing **1**.

For efficient operation of the wing unit, the three above described features are absolutely inseparable and they must be concurrently used. The wing unit thus provided virtually always gives the same thrust and ensures the same draft height even when one changes the speed, navigates in a rough sea and when, due to the rough sea, the water is subjected to orbital motions which influence the specific thrust with wings having a fixed incidence.

The embodiment of FIG. 4 differs from the embodiment of FIGS. 1–3, in that there is only a single wing unit provided, the wing unit being identical in every respect with the wing units of the embodiment of FIGS. 1–3. The single wing unit of FIG. 4 is positioned substantially amidships of the ship.

In FIG. 6 there is shown an example of the operation of the wing unit in which, for the present, the effect of the horizontal wing **10** has been omitted.

The total lift produced by the wing at a normal draft NN is denoted by S. Such lift is applied at the thrust center n at a distance x from the vertical plane passing through the axis of rotation. The active lift moment is given by the product $S \cdot x$. In addition, C denotes the force produced by the compression of the spring with y denoting the application arm thereof. The reactive moment is given by the product $C \cdot y$. The wing unit is in equilibrium if $S \cdot x = C \cdot y$. For sake of clarity, the drag of the wing in the water has been purposely neglected, since the moment thereof is of the same sign of that of the lift, has a noticeably lower value and, anyway, it may be assimilated to the lift moment.

Let it be assumed that in the crossing of a wave crest the draft of the wing, FIG. 6, moves from NN to AA and the lift center, due to the shape of the wing which extends forwardly, moves from n to a thereby reducing the application arm of the lift from x to z. By virtue of the additional lift produced by the wing surface submerged by the wave crest NNAA, the wing will rotate slightly abaft, that is toward the left side of the figure, and at the same time the spring will undergo a further compression thereby increasing the force from C to C′ and therefore the reactive moment from $C \cdot y$ to $C' \cdot y$. The lift center a by virtue of the wing rotation will be moved backwardly and the initial distance z will increase, let it be assumed for sake of clearity, until it again becomes x, by virtue of the backward rotation, the incidence angle of the wing decreases and consequently the specific lift produced by the submerged wing surface also decreases. Denoting by S′ the total lift produced by the draft AA, the new equilibrium position will be obtained when $S' \cdot x = C' \cdot y$. But, C′ by virtue of the greater compression of the wing, being greater than C, S′ should also be higher than S. In consequence, there being available a greater lift, the wing will tend to lift out of the water, returning from the draft AA to the normal draft NN.

Similarly, let it be supposed that in the crossing of a wave trough the wing draft, FIG. 6, will move from NN to RR and the lift center from n to r thereby increasing the application arm of the lift from x to t. In consequence of deficiency of lift of the wing surface NNRR, exposed by the trough, the wing will rotate ahead slightly, that is to say toward the right hand end of the figure, and at the same time the spring will undergo an expansion thereby reducing the force C to C″ and therefore the reactive moment will decrease from $C \cdot y$ to $C'' \cdot y$. The lift center r, due to the wing rotation, will have moved forwardly and the initial distance t will be reduced, let it be assumed for sake of clarity, until it again becomes x; again due to the forward rotation of the wing, the incidence angle of the latter increases and so also is the specific lift produced by the submerged wing surface. Denoting by S″ the total lift produced by the draft in RR, the new equilibrium position will be obtained when $S'' \cdot x = C'' \cdot y$. But, C″ due to the spring expansion, being smaller than C, also S″ should be smaller than S. Consequently, because there is available a smaller lift, the wing will tend to dive into the water, returning from the draft RR to the normal draft NN.

The evolute of the thrust centers is the line e, FIG. 6, which joins the points r, n, a, that is the line along which the thrust center moves upon the change of the submergance of the wing surface.

Other modifications of the wing unit structure are possible, for instance the coupling of the axles **4** to each other, or the axles **2** are joined to each other forming a single axle and the ends of the wings are also joined to each other. The unit will still act as described above.

Again, by way of example, be it assumed of embodying a wing unit as shown in FIG. 3, where the reactive moment is obtained by a compression spring which will be suitably loaded to create the reactive moment balancing the active moment due to the lift produced by the wing at the desired depth.

By way of numerical example let us assume that the portion of the weight to be supported by the wing unit will be 1000 kg., the lift produced by the wing when at the desired depth, with a given immersed surface and with a given incidence angle will be 1,000 kg., the arm of lever of the total lift 0.50 m.; the spring compressed at 500 kg., the arm of lever of application of the spring 1.00 m.

The active moment will be

$$1.000 \text{ kg.} \times 0.50 \text{ m.} = 50 \text{ kgms.}$$

the reactive moment will be

$$500 \text{ kg.} \times 1.00 \text{ m.} = 500 \text{ kgms.}$$

and therefore the moments are balanced and the system is in equilibrium.

Assume that the wing surface will enter a wave crest, increasing the immersed surface by 20%. If the wing were of the fixed incidence type, the lift would be increase by 20% reaching thus a value of 1,200 kg. against the 1,000 kg. forming the weight to be supported, imparting thus a sudden movement to the boat. By the wing unit considered in this invention, the operation is as follows: due to the greater immersion of the wing, and to the location of the wing surface, the center of the total lift moves forward reducing the arm of lever of application of the lift, say of 2% (factor 0.98) but since due to the greater instantaneous lift the wing unit will rearwards rotate up to the novel equilibrium position, also the center of lift will rearwards move together with the wing, increasing the arm of lever of application of the lift, say of 3% (factor 1.03); by the rotation of the unit, the spring will be further compressed, and due to its characteristics, say of 5% (factor 1.05); the arm of lever of application of the spring can be considered unchanged. If S is the lift at the novel location of equilibrium of the wing unit, the active moment will be:

$$S \cdot (0.50 \text{ m.} \times 0.98 \times 1.03)$$

the reactive moment will be

$$\text{kg. } (500 \times 1.05) \times 1.00 \text{ m.} = 525 \text{ kgms.}$$

Since the two moments, for the equilibrium, must be equal we will have:

$$S=\frac{525 \text{ kgms.}}{0.50 \text{ m.}\times 0.98\times 1.03}=\text{kgms.}$$

By the device according to this invention, the excess of the thrust with respect to the weight to be supported will be minimum and practically the lift can be considered constant.

Similarly, should the wing surface enter a wave trough reducing by 20% the immersed surface, with the fixed incidence wings the lift would be reduced to 800 kg., with a loss of 200 kg. of lift, while with the self-adjusting incidence wings by the same percents of change as above considered, the thrust would be

$$S=\frac{500 \text{ kgs.}\times \text{m. } (1.00\times 0.95)}{(0.50\times 1.02\times 0.97) \text{ m.}}=960 \text{ kgs.}$$

Also in this case the loss of lift with respect to the weight to be supported is minimum and practically the lift may be considered constant.

Also, it is to be considered that the lift increase or decrease, when passing the crests or troughs of the waves, being minimized by the quick elastic action of the wing unit according to the present invention, impart no movement to the boat or craft due both to the short duration of the greater or minor lift and to the inertia of the craft-mass.

The weight of a craft may change in function of the passengers load, the fuel load and so on. Considering again the preceding numerical example be it assumed that the weight at minimum load of the craft will be 4000 kg. to be subdivided into 1000 kg. for each wing unit, while the full load weight will be 4600 kg. to be subdivided into 1150 kg. for each of the four wing units. Be it assumed, also that the same immersion depth will be desired in any case for the wings; therefore to have a thrust of 1150 kg. instead of 1000 kg. at the same speed and for the same immersed wing surface, a greater incidence angle will be necessary, and this will be obtained by imparting a greater compression load to the spring determining thus a forewards rotation of the wing unit up to the new equilibrium position. Due to the rotation of the wing unit the center of lift, however reduces its application arm of lever, say, of 4% being reduced thus from 0.50 m. to 0.48 m.; the active moment to be balanced will be

$$1150 \text{ kgs.}\times 0.48 \text{ m.}=552 \text{ kgms.}$$

If C is the compression force of the spring and considering unchanged the application arm of lever of the spring at 1.00 m. we will have

$$C\times 1.00 \text{ m.}=552 \text{ kgms.}$$

wherefrom it may be assumed that the spring in its novel equilibrium condition must have a load $C=552$ kg. But, since in the rotation of the wing unit the spring has expanded reducing its load, say by 7% with respect to the original load, the difference of the compressive load to be previously applied will be:

$$552\times 1.07=500=\text{about } 90 \text{ kgs.}$$

In the practical embodiment the change of the compressive load to be imparted to the spring may be obtained, for instance, by moving the rest for the spring by a set screw, or by connecting the spring to the piston of a hydraulic cylinder and the latter to a hull structure or by any other known suitable system.

The data shown in the above specification of the operation of the unit have only exemplary and indicative nature, and changes could be entered without departing from the scope of the claims.

The lift of the wing system, as aforesaid, is basically depending upon the speed, the immersed wing surface and the incidence angle, but also other factors affect the lift: the streams generally and the general state of

smoothness and cleanness of the wing surfaces. Also these factors are always compensated for by the present invention since the wing will change automatically its incidence until reaching the desired lift.

At the start, being the specific pressure on the wings nul or minimum, the wing units will have a greater incidence angle, which may anyhow be limited, rendering easier the take off.

I claim:

1. In a ship having a hull, a self-adjustable hydrofoil wing unit comprising, an axle adapted to be rotatably mounted in said hull for rotation about a horizontal axis, an arm mounted on said axle and depending downwardly and rearwardly of said hull, a first wing mounted on the arm at the middle portion of said wing, said first wing extending outwardly and upwardly of said arm and forwardly relative to said hull and inwardly and downwardly of said arm and rearwardly relative to said hull, a fin connected between the upper forward end of said first wing and said arm where it is mounted on said axle, said arm extending below said first wing, a second wing mounted on the end of said arm and extending horizontally, a further arm mounted on said axle, and reaction means connected to said further arm for exerting a reaction force thereon to rotate said further arm around the axle in a direction opposed to the direction said arm will be rotated by the lift forces exerted on said wings.

2. A wing unit as claimed in claim 1 further comprising a stop positioned adjacent said further arm on the side thereof opposite said reaction means for limiting the movement of said arms when the hull is stationary or is accelerating to the planing condition.

3. A ship having a hull, a pair of self-adjustable hydrofoil wing units, one on each side of the hull and lying in a plane transverse to the centerline of the hull and adjacent the middle of the hull, each wing unit comprising an axle rotatably mounted in said hull for rotation about a horizontal axis, an arm mounted on said axle and depending downwardly and rearwardly of said hull, a first wing mounted on the arm at the middle portion of said wing, said first wing extending outwardly and upwardly of said arm and forwardly relative to said hull and inwardly and downwardly of said arm and rearwardly relative to said hull, a fin connected between the upper forward end of said first wing and said arm where it is mounted on said axle, said arm extending below said first wing, a second wing mounted on the end of said arm and extending horizontally, a further arm mounted on said axle, and reaction means connected to said further arm for exerting a reaction force thereon to rotate said further arm around the axle in a direction opposed to the direction said arm will be rotated by the lift forces exerted on said wings.

4. A ship as claimed in claim 3 in which the axles of said pair of wing units are connected to each other to form a single axle extending completely across the hull.

5. A ship having a hull, a first pair of self adjustable wing units one on each side of the hull and lying in a plane transverse to the centerline of the hull and passing through the bow portion of said hull, and a second pair of self adjustable wing units one on each side of the hull and lying in a plane transverse to the centerline of the hull and passing through the stern portion of said hull, each wing comprising an axle rotatably mounted in said hull for rotation about a horizontal axis, an arm mounted on said axle and depending downwardly and rearwardly of said hull, a first wing mounted on the arm at the middle portion of said wing, said first wing extending outwardly and upwardly of said arm and forwardly, a fin connected between the upper forward end of said first wing and said arm where it is mounted on said axle, said arm extending below said first wing, a second wing mounted on the end of said arm and extending horizontally, a further arm mounted on said axle, and reaction

means connected to said further arm for exerting a reaction force thereon to rotate said further arm around the axle in a direction opposed to the direction said arm will be rotated by the lift forces exerted on said wings.

6. A ship as claimed in claim 5 in which the axles of said pairs of wing units are connected to each other to form a single axle extending completely across the hull.

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