MECHANICAL CONTROL FOR SUBMERGED HYDROFOIL SYSTEMS

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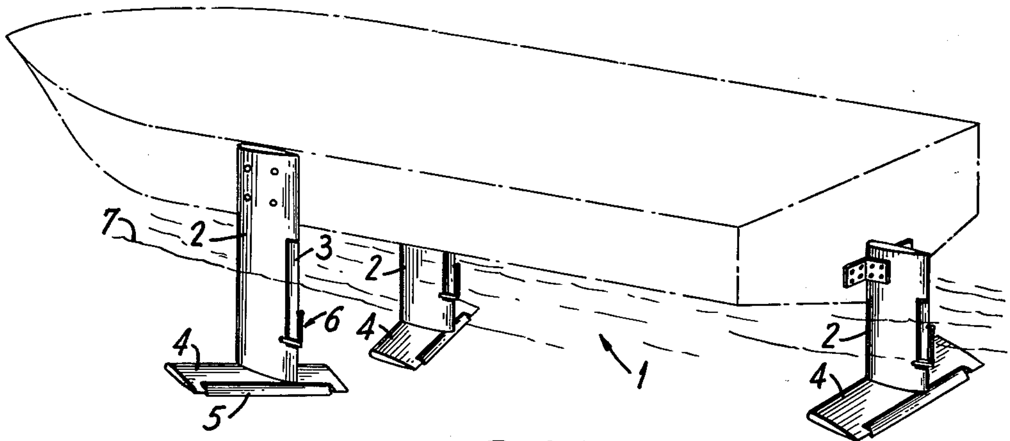

FIG. 1

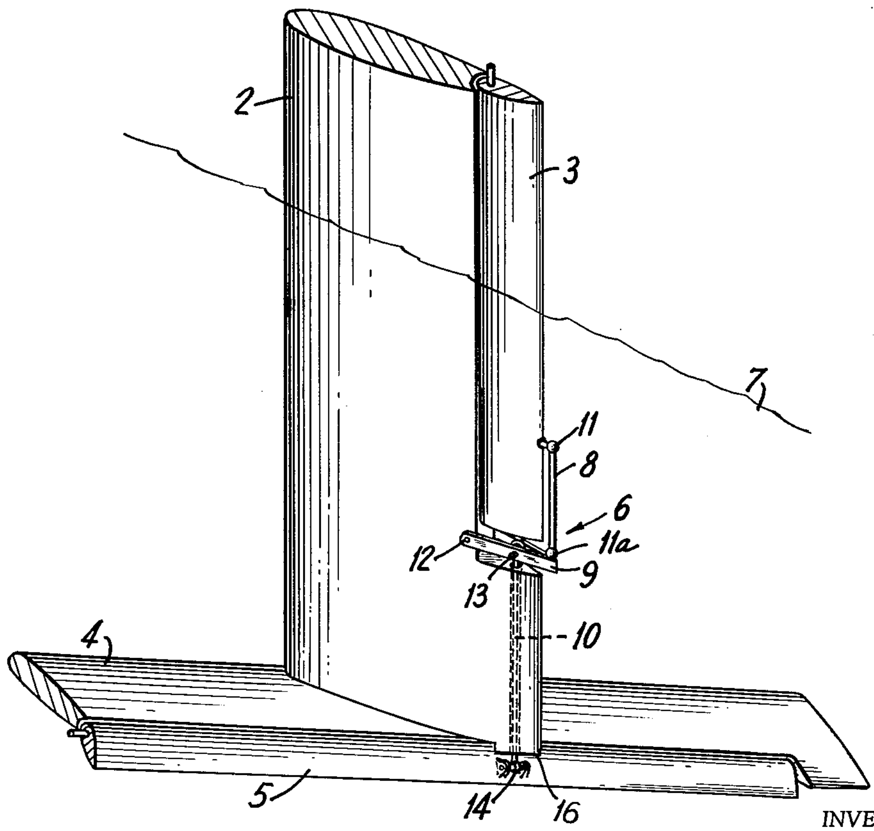

FIG. 2

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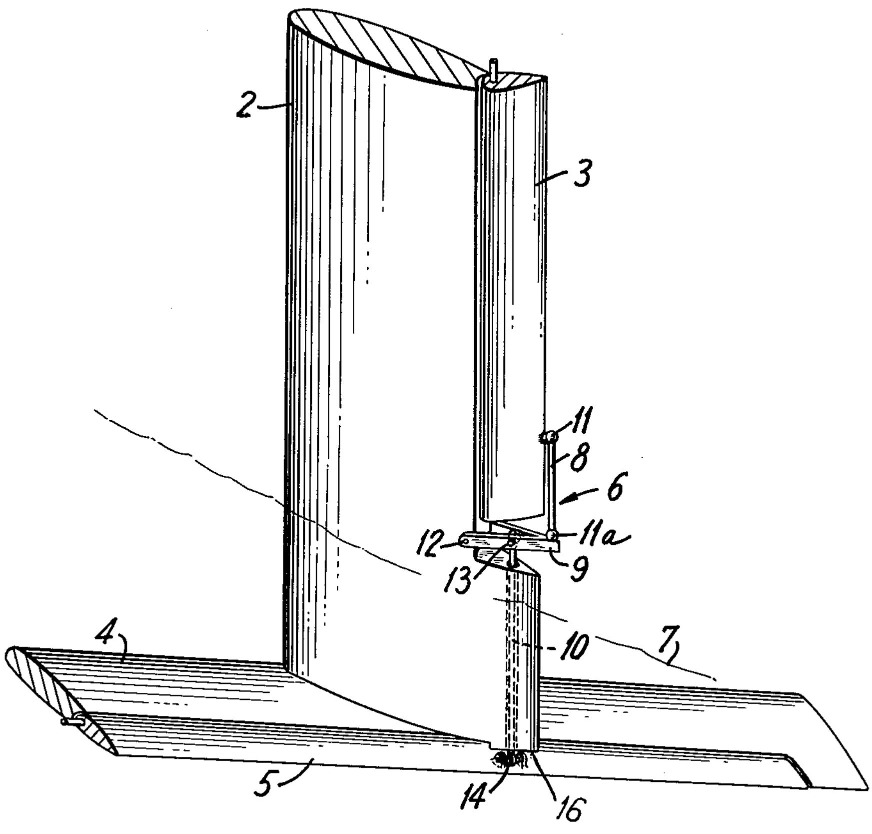

FIG. 3

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MECHANICAL CONTROL FOR SUBMERGED HYDROFOIL SYSTEMS

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The present invention relates to an automatic, passive, mechanical control system for stabilizing the motions of marine craft which are supported by submerged hydrofoil systems and which are subject to operation under either calm water or wave conditions.

In the operation of hydrofoil marine craft with uncontrolled submerged hydrofoil support systems, it is known that the craft requires some form of height stabilization control when operating in either smooth water or waves. In smooth water uncontrolled submerged hydrofoil systems may develop continuously oscillating heaving and pitching motions or so-called divergent pitching or heaving motions which may cause the hull of the hydrofoil craft to either crash on to the water surface or cause the submerged hydrofoils to suddenly emerge through the water surface—again resulting in the crash of the hull against the water surface. When uncontrolled submerged hydrofoil systems are run in a seaway, the wave disturbing forces can either result in extremely uncomfortable heaving and pitching motions of the craft and/or cause the bow of the hull to crash onto oncoming wave flanks. All the above described events can seriously hamper or prevent successful operation of the hydrofoil boat. In the past, many attempts have been made to control the hydrodynamic forces on the submerged hydrofoil by the use of combined electronic and mechanical control systems. These control systems usually sense the disturbance of the craft by continuously monitoring (usually electrically) the accelerations or motions of the craft and then, by mechanical means, provide for effective angle of attack changes on the submerged foils to vary the hydrodynamic disturbing forces on the hydrofoil in order to overcome the wave disturbances. These electronic-mechanical auto-pilot systems are usually complex in design; require continuous maintenance; are costly; and may cause a hydrofoil boat to be inoperable if only one of the many of its components is defective.

A feature of the present invention is the provision of a passive, mechanical, automatically operating simple hydrofoil control system which possesses all the advantages of a submerged hydrofoil system without the complexity, expense, and involved maintenance required of present electronic-mechanical autopilot systems. To attain this, the present invention consists of mechanically linking a control flap on the submerged hydrofoil to a vertical trailing edge flap on the vertical strut which supports the submerged hydrofoil to the hull of the craft.

In smooth water operation, as the hydrofoil boat tends to fall towards the water surface, the vertical flap on the vertical support strut is so arranged as to be deflected by the hydrodynamic force developed by the increased effective immersion of the flap. Through a suitable linkage system the deflection of the vertical flap causes a deflection of the control flap on the submerged hydrofoil thus increasing the hydrodynamic lift on the hydrofoil causing the hydrofoil craft to rise until an equilibrium altitude is attained. At some preselected operating height of the boat, the vertical flap is designed to be clear of the water and the height stabilization is achieved by the natural hydrodynamic phenomena wherein the submerged hydrofoil loses hydrodynamic lift as it approaches the free water surface and gains lift as its submergence is increased.

In operations in waves the rising water surface of the

wave profile actuates the vertical flap so that its deflection causes a deflection of the flap of the submerged foil which in turn increases the hydrodynamic lift force on the submerged hydrofoil so as to raise the hull over the oncoming wave flank. The size of the submerged hydrofoil control flap, the size of the vertical depth control flap on the vertical support strut and the required mechanical linkages between these flaps are arranged and proportioned to provide any desired sensitivity and response characteristics to wave disturbances as to assure a minimum total craft response to the hydrodynamic forces developed by operation in waves.

Another feature of my invention is the provision, by the proper proportionment of the various elements of the control system, for any desired degree of response to the various wave systems to be encountered.

A further feature of the invention is a passively activated hydrofoil flap control which will automatically provide for large hydrofoil lift coefficients at low speed and also provide for low lift coefficients at high speed or cruise condition.

An additional feature is a completely mechanical self-operating control and stabilizing system for submerged hydrofoils in which the depth sensing element is not affected by the vertical orbital velocities in the wave system.

Other features and the attendant advantages of this invention will be readily appreciated by reference to the following description when considered in connection with the accompanying drawings wherein:

FIGURE 1 shows a schematic view of a preferred embodiment of the invention as installed on a hydrofoil boat;

FIGURE 2 shows a schematic detailed view of a preferred embodiment of the invention when operating at speeds and submergences when the vertical flap is partially submerged;

FIGURE 3 shows a schematic detailed view of a preferred embodiment of the invention when operating at speeds and submergences such that the vertical flap is not submerged.

Referring now to the drawings wherein like reference characters designate like or corresponding facts throughout the several views, there is shown in FIGURE 1 a submerged hydrofoil 4, attached to a vertical support strut 2, which in turn is attached to the hull 1. A vertical flap 3, is attached and pivoted at the trailing edge of the vertical support strut 2.

A trailing edge control flap, 5, is attached to the trailing edge of the submerged hydrofoil 4. A mechanical linkage generally indicated as 6 is connected between the vertical flap 3, and the horizontal flap 5. The details of the linkage 6, are shown in FIGURES 2 and 3.

The operation of this linkage system 6 is as follows: When the surface craft altitude is such that the free water surface 7 intersects a portion of the vertical flap 3, the hydrodynamic loads on this flap cause it to pivot about its vertical axis. This flap motion causes a ball joint 11, which is attached to the vertical flap, to rotate in a horizontal plane. A rigid rod 8, which is fixed in length, is connected to the flap ball joint 11, at its upper end, and at its lower end, to a similar ball joint 11*a* attached to a lever 9, which is limited to movement in a vertical plane. The lever, 9, is attached through a pivot 12, disposed on the vertical strut 2. When the vertical flap 3 is deflected then the rod 8, causes the lever 9, to move up or down depending upon the direction of rotation of the flap 3. A vertical rod 10, is connected to a point on the lever 9 by a pivot pin 13. The lower end of rod 10 is pivotally connected to the submerged hydrofoil flap 5, by another pivotal connection 14.

By proper design of the basic linkage system 6, the hydrofoil flap deflection rate can be made to be any desired proportion of the vertical flap deflection rate.

In low speed operation, as illustrated in FIG. 2, the vertical flap 3, is immersed in the water and the hydrodynamic load on this flap causes a full down deflection of the submerged hydrofoil flap 5. The full deflection of the flap 5, causes a large lift coefficient to be developed by the submerged hydrofoil. The large lift coefficient on the submerged hydrofoil develops a large hydrodynamic lift force so that hydrofoil boat 1, tends to lift itself out of the water. As the speed of the craft is increased, two conditions are developed: one is, that the required lift coefficient to support the craft is decreased and secondly, the craft will start to rise so that the hull is lifted out of the water. As the craft rises, the vertical flap 3 rises, immersion is reduced and its hydrodynamic load is reduced. The increased load on the submerged flap 5 then causes its own deflection to be reduced and in turn, through the linkage system 6, causes the vertical flap to increase its flap angle until an equilibrium moment condition is achieved between the vertical flap and horizontal flap loads. This process continues, i.e. as the craft goes faster, the hydrofoil flap 5, loads are increased, the craft rises, reducing the effectiveness of the vertical flap 3 until the craft reaches an equilibrium cruise height at which the vertical flaps are completely out of the water and the hydrofoil flap is no longer deflected, its further movement being prevented by a physical upper stop 16 (FIGS. 2 and 3).

Further increases in craft height are then controlled by the hydrodynamic phenomena which causes a reduction in hydrofoil lift as the submerged dihedral hydrofoil approaches the free water surface. If, for some reason the craft is caused to move towards the free water surface, the vertical flap 3 is then actuated causing a deflection of the hydrofoil flap 5, which in turn causes the hydrodynamic lift force to be increased and hence causes the craft to rise again to an equilibrium condition. As can be seen from the above explanation, the present invention is an entirely passive and mechanical height stabilizing system for submerged hydrofoil systems.

When operating in waves the dynamics of the control system will develop a desired low response to the high frequency of wave encounter associated with high speed operation in waves, and hence achieve "stable platform" operation. These low responses to the high frequencies of wave encounter will be especially beneficial when operating in short wave lengths and hence the motions of the craft and loads on the craft will be very much reduced compared to a surface-piercing hydrofoil system which is directly loaded by each wave it encounters. For long waves, where the frequency of encounter is small, the dynamics of the control system will respond to these

long waves so that the hydrofoil craft will essentially "contour" these waves. The dynamics of the control system are controlled through proper linkage design and mass distribution in the flaps. It is obvious from the above description that the vertical flap control system in the present invention is insensitive to the vertical orbital velocities of the wave system.

I claim:

1. In combination with a water borne vessel, a passive self-compensating hydrofoil control system comprising a substantially vertical hydrofoil strut member and a hydrofoil plane, said vertical strut member being connected at its upper end to the hull of said vessel, said hydrofoil plane being disposed at the lower end of said strut member and operable to maintain a hydrodynamic lift of the vessel to a minimum submergence of the hydrofoil plane below the free water surface at cruise speed of the vessel, each of said strut and plane members having integral pivotal flaps defining at least a portion of the trailing edges of said members, said pivotal flap of the strut member terminating at its lower end at a height above said hydrofoil plane which is greater than said minimum submergence, and mechanical linkage means interconnecting both of said pivotal flaps and operable, on application of unbalanced external forces to one flap causing it to pivot, to apply to the other flap a force acting to move said other flap toward a position for equalizing the forces applied to both flaps.

2. The combination according to claim 1 wherein the mechanical linkage means interconnecting said flaps includes means for producing a mechanical advantage.

3. The combination according to claim 1 wherein said mechanical linkage means comprises a first push rod, an intermediate lever and a second push rod, one end of each of said push rods being pivotally connected to one of said flaps and the other end of each of said push rods being pivotally connected to said intermediate lever.

4. The combination of claim 3 wherein the means interconnecting one of said push rods with its respective flap and said lever are ball and socket joints, whereby rotational movement of said flap is converted into unidirectional movement of said lever.

5. The combination according to claim 1, comprising also a stop for limiting pivotal movement of said flap of the hydrofoil plane in the upward direction.

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