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Murray

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[54] **SAILING BOATS WITH RIGID SAILS**

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Jan. 8, 1971	Great Britain	1070/71

[52] **U.S. Cl.** **114/39**
[51] **Int. Cl.** **B63h 9/06**
[58] **Field of Search** .... 114/39, 102, 103–108, 114/144 R, 144 C

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[57] **ABSTRACT**

A sailing craft has a rigid sail assembly mounted for free rotation about an upright axis and a tail vane rotatably carried on the assembly for adjusting the incidence of upright aerofoil elements to the apparent wind. A counterweight for mass balancing the assembly is arranged above the bottom of the assembly so as to balance, with respect to the main upright pivot axis, the products of inertia about each of the two orthogonal axes which are orthogonal to the main axes. In the preferred form, a triplane arrangement is used for the aerofoil elements with the centre element forward of the outer elements. Use is made of aerofoil sections of larger leading edge radius than normal. A control system for the tail vane has two control levers, for use respectively on port and starboard tacks, which are interconnected to move in opposite senses so as to give a simple control connection. A governor is provided for limiting the maximum tail vane movement in accordance with wind strength.

5 Claims, 5 Drawing Figures

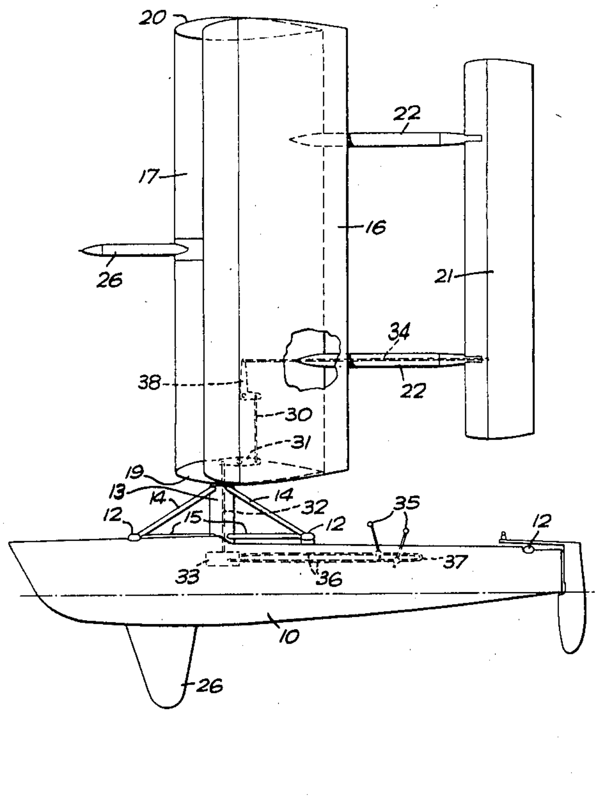

Fig. 1.

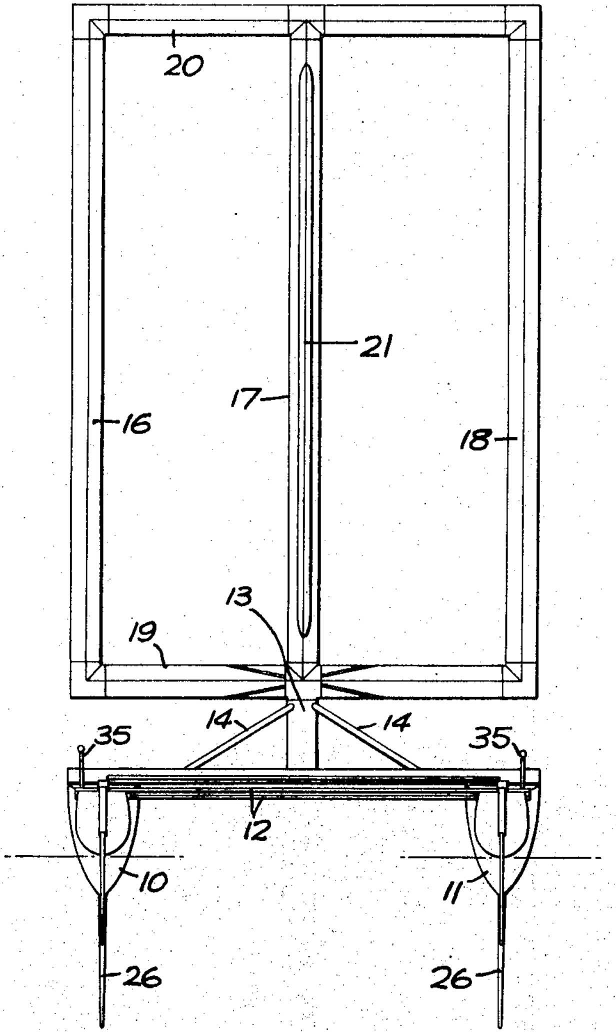

Fig. 2.

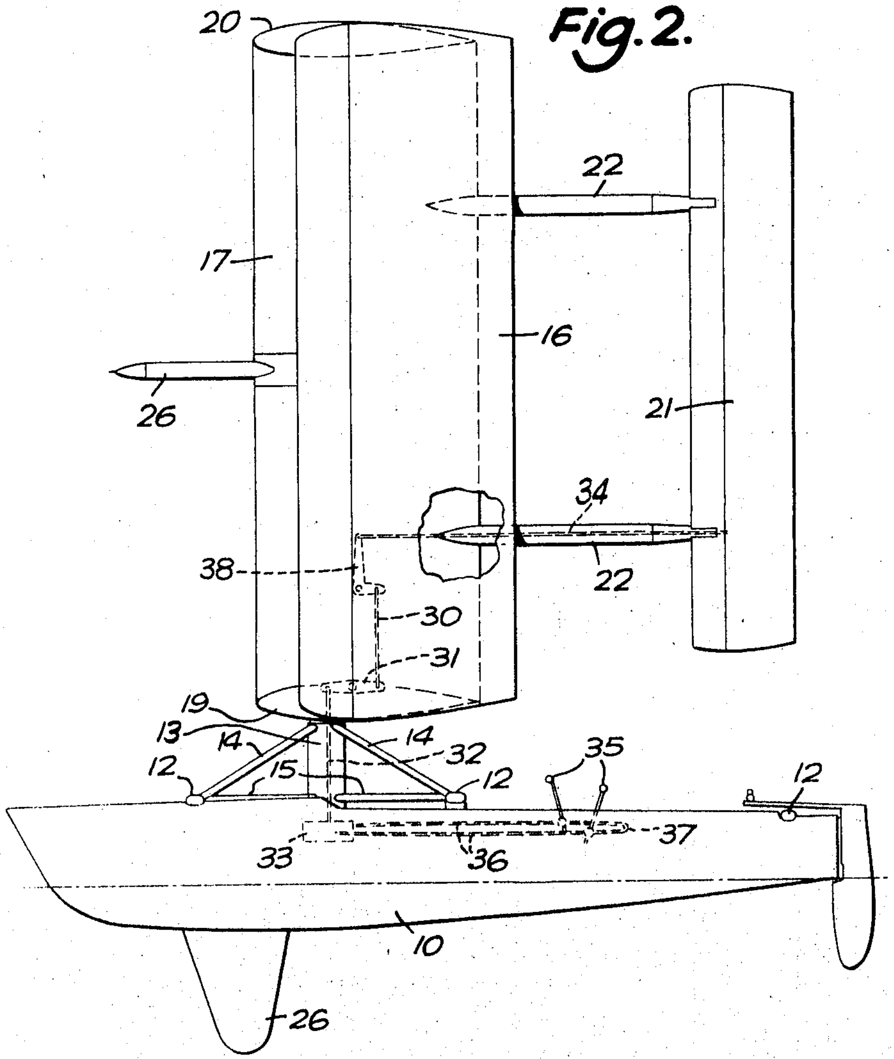
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Fig.3.

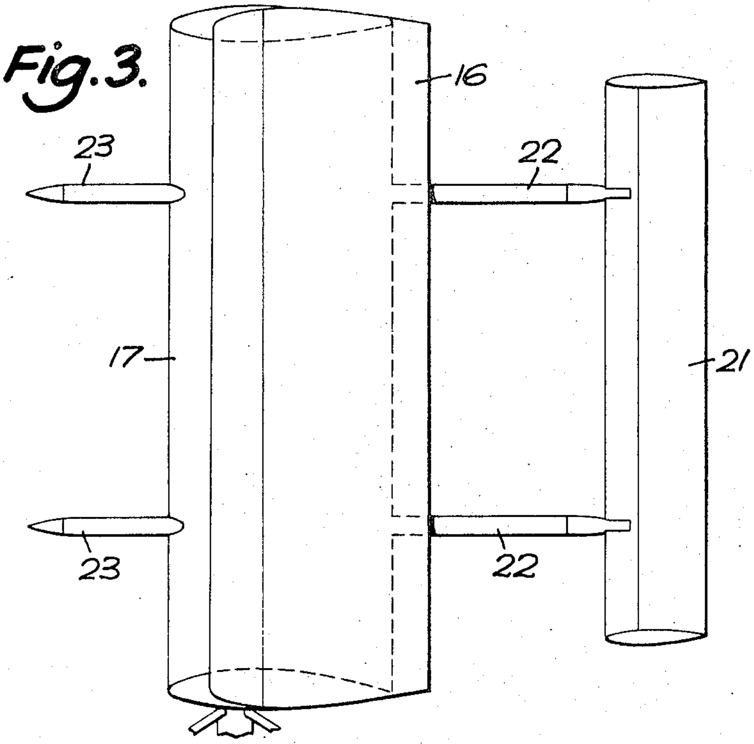


Fig.4.

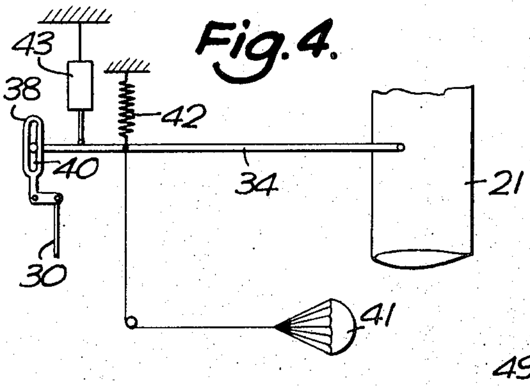
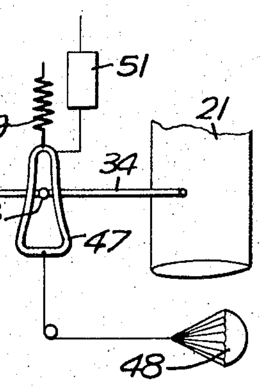


Fig.5.



SAILING BOATS WITH RIGID SAILS

BACKGROUND OF THE INVENTION

1. Field of the invention

This invention relates to sailing craft with a rotatable sail assembly consisting of one or more rigid upright aerofoils.

2. Prior art

Such craft are described in British Patent No. **198649** (Anton Flettner). In such a craft there is provided a rigid sail assembly rotatable on a vertical or near vertical pivot, the angle of incidence to the relative wind of its vertically or near vertically extending aerofoils or aerofoil being controlled by an auxiliary (vertical or near vertical) aerofoil which is mounted on rigid struts from the said assembly, either upwind or downwind from the main aerofoil(s) and hereinafter called the tail vane regardless of which position it may occupy.

With a rigid sail element or elements mounted so as to be freely rotatable, static and dynamic balancing of the system is desirable. One requirement is to mass balance the assembly so that it will not tend to rotate due to static gravitational attraction if the main pivot tilts out of the vertical. Dynamic balancing is also necessary so that the system will not rotate under transient angular accelerations. These considerations lead to the putting of a counterweight on the rotating system in the axis of symmetry (considered in a horizontal plane) ahead of the main pivot axis. It will be appreciated that almost universally, and particularly in a "tail aft" system, the mass tends to lie aft of the pivot axis. Heretofore designers have put such a counterweight low down to enhance the general stability. However the result of pitching or rolling acceleration causes a low counterweight to tend to rotate the sail assembly.

SUMMARY OF THE INVENTION

According to one aspect of the present invention in a craft having a freely rotatable rigid said assembly, a counterweight for mass balancing the rotatable assembly about its main pivot axis is positioned substantially above the bottom of the rotatable assembly to balance the assembly under pitching or rolling accelerations not only about the main pivot axis but also to balance, with respect to that axis, the products of inertia about each of two orthogonal axes which are orthogonal to said main axis. This counterweight may be distributed. In other words, in addition to mass balancing about the main pivot axis, which may be considered as the Z axis in a three dimensional (XYZ) co-ordinate system the products formed by the moments of inertia about the X axis multiplied by their respective Z co-ordinates are balanced and likewise the products formed by the moments of inertia about the Y axis multiplied by their Z co-ordinates are also balanced.

The invention is applicable not only to water-borne craft but also to sail propelled vehicles fitted with wheels for use on land or fitted with skates for use on ice.

It is fundamental to sailing craft that the sails (except in cases of excessively high winds) operate at high values of the Lift coefficient. When so doing, the major proportion of the Drag coefficient is the induced component which is inversely proportional to the effective aspect ratio of the sail assembly, so that a high effective aspect ratio leads to a low induced drag and higher efficiency. A direct increase in the geometrical aspect ratio however, by increasing the span or height of the sail assembly, carries a penalty in imposing a greater overturning moment on the craft or vehicle, so that for a given stability, an increase in span must be accompanied by a reduction in area of the sail assembly.

According to another aspect of the present invention, a rigid sail for a sailing craft has an endplate on at least one end of a vertical sail element or elements. At the upper end of the sail element, the endplate may conveniently be a member or structure of generally aerofoil section arranged substantially horizontally at an angle to give zero or slight positive lift and extending transversely of the chord of the sail element. If there are two or more vertical sail elements, the endplate may extend between them and possibly extend beyond the sail elements. At the lower end of the sail element or elements a similar endplate may be provided but in some cases the craft structure or turntable for the elements may act aerodynamically as an endplate.

This construction enables a high effective aspect ratio to be achieved on a moderate span. Despite the increase in parasitic drag occasioned by the endplates themselves, the induced drag is thereby reduced by more than this, so that in normal sailing conditions at a high lift coefficient, there is a net reduction in total drag from such a rigid sail assembly.

Control system problems arise in sailing craft with rigid sails controlled by a tail vane. One of these is that in sailing it is important to know the tack being sailed and the angle between the relative wind on that tack and the heading of the craft being sailed. Wind indicators per se are not new but it is important in conjunction with rigid sailed yachts to have a control system and control convention which assures that the correct action is taken to increase or decrease the sail thrust and hence speed, in either the ahead or the astern sense. Additionally the drive thrust should not be allowed to become excessive which might otherwise cause the craft or vehicle to suffer a capsize, or cause structural failure of the rigid sail system itself.

According to yet a further feature of the present invention in a sailing craft with a freely rotating assembly of rigid aerofoils controlled by a tail vane on the rotating assembly, the tail vane is controlled by control means including first and second control levers for use on port and starboard tacks, the levers being interconnected so that moving one in one direction causes the other to move in the opposite direction. For a craft with the control tail vane aft of the main aerofoils, preferably the levers are arranged so that the first when moved forward causes the tail vane to move anticlockwise as seen from above and the second, when moved forward causes the tail vane to move clockwise when seen from above. If the control tail vane is forward of the main aerofoils, the senses of movement are preferably reversed.

A hydraulic swivel may be used which will both carry hydraulic fluid (e.g., for power for folding down the system) and provide the control function for the tail vane.

Means may be provided responsive to the wind speed and operative on the control linkage to reduce the demanded thrust from the sail when wind speed exceeds a predetermined value. Such means, forming in effect a governor, provides a safeguard against capsizing or damage due to setting the sail to produce too high a thrust. Conveniently these means are operative to maintain the demanded thrust constant or nearly constant irrespective of the wind speed, this constant thrust being pre-set at a designed or predetermined 'safe' limit.

To prevent the tail vane rotating independent of the desires of the driver as expressed by his choice of control setting, a mechanical friction device of low efficiency may be provided in the control linkage so that, while the control inputs can move and control the tail vane, under no circumstances can an inadvertent movement of the tail vane occur which would backdrive the control linkage and so move the control input.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an end elevation of a catamaran with rigid sails;

FIG. **2** is a side elevation of the catamaran of FIG. **1** with the sails in a different angular position; and

FIG. **3** is a side elevation of the sails of a modification of the construction of FIGS. **1** and **2** with a distributed counterweight; and FIGS. **4** and **5** are diagrams showing in further detail parts of a control linkage.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In the drawings, the catamaran has two hulls **10, 11** joined by cross members **12** and with a main pivot bearing **13** for a rotatable sail assembly. The upper end of the bearing is supported by the upper elements **14** of a quadrupod. The lower end of the bearing is supported by elements **15** forming diagonals in the rectangle made by two hull elements **10, 11** and main crossbeams **12**. The double-A frame formed by opposing pairs of upper and lower elements **14** and **15**, with the bearing **13** add significantly to the strength of the interhull structure and provide a three-dimensional triangulated structure that can easily be both light and rigid, while being adequately strong.

An endplated triplane assembly mounted upon the main pivot **13** has the three rigid aerofoils **16,17,18** connected at the bottom by an endplate **19** and at the top by an endplate **20.** The endplates join all three aerofoils at square corners, which may be filleted or rounded if desired, so as to provide a box-like structure with all the main aerofoils **16, 17, 18** and the endplates **19, 20** pointing substantially in the same direction. In this triplane arrangement, the two structural bays may have bracing stays across them. The centre aerofoil **17** may be made considerably stronger and stiffer than the two outer aerofoils although not necessarily of different section, so that the additional structural material can be deployed inside a similar section to the outer aerofoils **16, 18.** The centre aerofoil **17** will then bear a more than proportionate share of the structural load of the whole assembly, and this can be distributed laterally to the two side aerofoils by means of structure inside the endplates, which may themselves be of aerofoil section. By this means, more of the structural weight can be distributed closer to the main pivot axis **13,** which will reduce the rotating inertia of the whole rigid sail assembly and improve its dynamic response. FIG. **2** shows a tail vane **21** mounted on two (in this case downwind direction) projecting booms **22** extending from the centre aerofoil **17.** This tail vane is hinged about its own axis and it is deviations from the perfect alignment of this tail vane which cause the whole sail assembly to achieve an incidence to the relative wind and hence to develop a significant resultant thrust to drive the craft or vehicle.

The centre aerofoil **17** has been set a little further ahead than the two outer aerofoils **16, 18.** This arrangement (which is also applicable to systems with four and five aerofoils) achieves a better sharing of the load between the three aerofoils and with this a more even sharing of the drag, so that there may be less drag couple acting about the main pivot which would otherwise have to be counteracted by the tail vane **21.** It also increases the distance between the centre aerofoil **17** and the tail vane **21** and so relieves the latter of some of the adverse effects of the wake of the former. It may also confer structural advantage in that the thickness of the centre aerofoil in the region of the centre main spar (the most important vertical member if the technique described above is used) may be increased, as in effect the centre aerofoil in this arrangement is moved forward relatively about twice as much as the outer aerofoils are moved back. In addition it may improve the attractive appearance of the whole assembly by making it less severely rectilinear.

The endplates themselves may be of asymmetrical section and/or be set at a slight incidence so that they may derive some lift.

Whereas it will normally be found more convenient to have the upper of the two endplates fixed to the main aerofoils rigidly, it is possible to achieve the same aerodynamic effect at the lower end provided that the structure of the craft or vehicle itself interposes effectively to prevent a significant escape of air around the lower edges of the vertical aerofoils. This will prevent strong vortices forming at these 'wing tips' and so have the desired effect of raising the effective aspect ratio, provided that any gap that may exist is small by comparison with the span, say not exceeding 5 percent.

A large diameter bearing or turntable may be provided for the main pivot, and, in this case, it may be found advantageous to dispense with all or part of the lower endplate, incorporating it in the combined craft or vehicle structure and main pivot complex so described.

For the aerofoils, I prefer to use an aerofoil section similar to the NACA 4-digit series with a maximum thickness lying at between 15 percent and 50 percent of the chord from the leading edge, of symmetrical or nearly symmetrical section with the camber not exceeding ± 4 percent of the chord, the maximum thickness being between 12.5 percent and 17.5 percent of the chord and which has any slope and thickness at the trailing edge but has a leading edge radius r (measured as a multiple of the chord) given by the formula

$$2.10125\, t^2 \geqslant r \geqslant 1.20125\, t^2$$

so that

$$r = \tfrac{1}{2}\, [t\, a_o/0.2]2$$

where t is the maximum thickness expressed as a multiple of the chord and a_o lies in the range 0.31 to 0.41 which specifically excludes the classical sections:- **0012, 0015, 0018, 0012B** and **0018B.** For an aerofoil with a maximum thickness of 15 percent of the chord, the leading edge radius is preferably **0.0356** compared with **0.0248** of an NACA **0015** section.

Rigid sail systems having a freely rotatable sail controlled by a tail vane are inherently very safe and docile, provided that they only rotate in response to the operator's commands, and/or changes in the wind, and do not rotate as a result of any other external static or dynamic influences. Obvious features are therefore free rotation in low-friction bearings, adequate tail vane authority and control stiffness, low rotating inertia and also adequate aerodynamic (usually and principally from the tail vane itself) and/or artificial rotational damping etc. In my construction, special techniques are used to completely balance the whole assembly during the course of the design. In fact such designs should be balanced in no less than seven different ways. Two of these ways are aerodynamic and mass balance of the tail vane itself and its control system. A third mode of balancing is the obvious one of aerodynamic balance of the whole 'wing-tail' assembly, which is classical and identical to the short-term (dart) longitudinal stability of an aircraft or missile. A fourth and fifth are the need to mass balance the assembly so that it will not tend to rotate due to the static gravitational attraction (assumed to work in the true vertical) due to any deliberate or inadvertent, permanent or transient tilting of the main pivot out of the true vertical or lateral or longitudinal linear accelerations. This problem is handled by consideration in two orthogonal planes, along and across the sail system.

In this process a set of axes are nominated conveniently defined as the axis of the main pivot and two additional orthogonal axes lateral and longitudinal with respect to the axis of symmetry and coincident with the junction of the chord of the lower endplate (or the deck of a turntable) and the main pivot axis. As already described, balancing actions four and five consist of ensuring that the sum of the moments of all elements of rotating mass lie on the main axis, i.e., there is as much moment ahead as behind and on each side also an equal amount. This action will in most practical designs result in the necessity to add mass ahead of the pivot, certainly in conventional or 'tail aft' systems.

Thus far is not original, and in a number of previous designs in this field has given rise to some form of forward counterweight. All previous designers however have decided to keep this counterweight as low as possible (to enhance general stability) and have thereby fallen into a fundamental error. In order to achieve the whole aim set out above, it is necessary to also balance the whole system dynamically so that it will not rotate under the influence of any transient angular accelerations that may be imposed by unevenness of the surface of the sea, land or ice etc. The result of a pitching or say rolling acceleration will prevent a heavy low forward counterweight from balancing the high aft structural masses and they will hang back due to their own inertia and so set up a tendency to rotation of the whole assembly about the main pivot. This can give rise to dangerous divergent oscillations. I therefore raise this counterweight to that point which will give the same product of inertia about any two of the combinations of main and either of the other two axes as already defined, so that there is no tendency to rotation from this cause.

In the drawings, a single counterweight **26** is shown but it could be equally well replaced by two or more such weights distributed in any desired fashion to achieve the above result.

In FIG. 2 there is shown the control system for the tail vane **21.** Such a construction using two weights **23** forward of the main aerofoils **24** is illustrated in FIG. 3. Concentric or nearly concentric with the pivot **13** there is a vertical or near vertical column **32,** the upper part of which rotates with the sail assembly but is free to be moved vertically (axially) by means of a lever **31.** The column **32** is mechanically linked (via lever **31,** a bell crank **38** and rods **30,34**) to the tail vane to rotate the latter about a vertical axis when the column **32** is moved vertically. Column **32** is preferably a tube and this may contain fluid conduits connected via a hydraulic swivel **33** to a system of hydraulic jacks for folding the rigid sail assembly in any of a number of ways. The hydraulic swivel thus may also serve the purpose of carrying a supply of hydraulic power into the rigid sail assembly as well as serving in its primary function as a control push-rod for controlling the tail vane. Some form of swivel is necessary in any case for the latter purpose, and by employing a hydraulic one, the number of moving parts required to introduce hydraulic power can be greatly reduced, making the device more mechanically simple and reliable.

The column **32** is actuated by two control levers indicated diagrammatically at **35** through a system of cables or pushrods **36.** These levers are situated at a control, driving or pilotage position, where they can be grouped with a steering control for the craft or vehicle and where any necessary instruments may be displayed. A suitable arrangement of these levers would be to place them one on each side of a control panel in front of the helmsman or driver's seat or, as is illustrated, one in each hull. The two levers are interconnected by a loop **37** so that moving either lever forward or backward, automatically moves the other lever in the opposite direction.

The connection of the control column to the tail vane is such that when the craft or vehicle is on say the starboard tack, (defined as with the wind coming from the starboard side) the starboard lever **35** will cause the tail vane to move in such a direction (clockwise as seen from above) as to cause the sail system to take up an angle of attack to the relative wind (anticlockwise as seen from above) that will cause forward thrust on the vehicle, when the said lever is moved by the operator or driver in the natural or forward sense. Moving the starboard lever **35** in the other direction (natural reverse sense) will cause the converse, i.e., the sail system will produce reverse thrust on the craft or vehicle. The port lever **35** during this process would be moving in the opposite sense, but because the craft or vehicle is on the starboard tack would be ignored.

Then when on the port tack, when the required rotation of the sail system and tail vane are reversed, the port lever **35** would be used in the natural sense (forward for ahead, and rearward for reverse thrust) while the starboard lever **35** would be ignored.

The directions of rotation of the tail vane described above refer to the conventional or 'tail-aft' configuration. If a canard or 'tail-forward' configuration is used, then the directions of rotation of the tail vane will have to be reversed, in order to have the same effects.

A simple indicator such as a flag or vane may be provided forward of the control position, in a position exposed to the natural relative wind to show which tack the vessel is on.

Its provision, with colour coded faces if so desired facilitates the use of paired control levers for the control of a rigid sail system, so that they may be operated in a natural sense.

The levers 35 may be arranged one in each hull or they may be in a central control position. Preferably a non-linear linkage system is used so that a substantial part of the range of movement of each lever causes movement of the tail vane within the normal (non-stalled) condition, e.g., over 8° of tail vane movement to obtain 18°–20° of wing incidence, whilst still permitting of substantial movement e.g., 30° of tail vane to give 50° of wing incidence, to obtain deep stall conditions when running before the wind.

In higher wind strengths, the maximum thrust may be too much for the lateral stability of the craft or vehicle, so that it may capsize. Alternatively it may provide more thrust than the physical strength of the sail system can stand, and in order to allow for this case, a governor mechanism may be installed between the operator's controls and the actual tail vane. Fundamentally, the governor consists of a wind strength measuring device, of adequate dimensions to operate a linkage which provides an analogue of the wind strength. The linkage is connected in the form of a dividing network (or multiplying by the reciprocal), so that when the wind strength rises above a safe preset limit, the output linkage to the tail vane is an analogue of the input linkage from the operator's controls divided by the excess of wind strength.

For example, in FIG. **2,** where the push rod **30** may operate a bell crank **38** the upper arm of which may be slotted as shown at **40** in FIG. **4.** The output push rod **34** to the tail vane slides at one end in this slot and it can be seen that with the output push rod **34** when at the upper end of the slot will give the maximum ratio of output to input. When at its lowest position in the slot with least advantage or leverage, the ratio of output to input is at a minimum. Intermediate positions give rise to proportional ratios between maximum and minimum. In operation in a simple fashion, the wind strength measuring device may be a plain drogue **41** or cup, which is sensitive to drag and not very sensitive to small changes in the relative wind direction. The drogue can then be mounted on the sail system so as to rotate with it, the drogue being arranged so that increased pull on the drogue pulls down the forward end of the rod **34** in the slot in bellcrank **38.** It is restrained from doing this by a simple spring **42** which can just be overcome at the preset 'onset of governing action'. It may also be advantageous to insert a damping device **43** (possibly of a viscous nature) in parallel with the spring or elsewhere in the linkage system to eliminate any tendency for the analogue system to oscillate.

The wind strength sensitive device could take one of several forms. Another form is a venturi where the pressure difference engendered by changes in the wind strength is used to move a diaphragm in a plenum chamber which in turn is connected by a flexible tension element to the forward end of the output push rod **34.** Another method is by use of lift on an auxiliary wing which may either be held at a fixed incidence or be mounted on its own pivot so that it may be automatically trimmed to a constant incidence by its own small tail vane. This device can conveniently be mounted on the trailing edge of a wing or strut such as the centre panel of a triplane arrangement on a slide so that the lift force will cause it to move along the slide and by connection move the forward end of the output push rod **34** from top to bottom of the slot as before. The auxiliary wing may be of cambered form in which the 'pitching moment' characteristic of an unsymmetrical wing section produces a moment depending on the wind strength.

All of these aerodynamic devices exhibiting properties of a wing (drag, pressure difference, lift and pitching moment) provide forces or moments which are principally proportional to the square of the wind velocity. They are therefore capable of correctly controlling the force from the main wing aerofoils by acting inversely on the incidence of the latter (through a dividing link and subsequent action on the tail vane), the incidence and hence lift force of the main wings being directly controlled by the tail vane.

Another form of governor which may prove simpler to construct, although it does not have all the advantages of the above-mentioned proportional version is one which limits the maximum excursions of the tail vane. One such a device as shown in FIG. **5,** there is a proud pin **46** on the connecting rod **34** from the bell crank **38** to the tail vane **21.** A shaped link **47** is provided to limit the axial movement of the rod **34,** the length of such movement being determined by the shaping of the link and its position in a direction transverse to the rod **34.** This link is caused to slide in the vicinity of this pin and approximately at right angles to the movement of the connecting rod **34,** for example by a drogue **48** or other device as previously described acting against a spring **49** with an optional damping device **50** in parallel. This link **47** will limit the maximum travel of the connecting rod **34** so as to prevent the operator from selecting too great a thrust for the prevailing relative wind strength, and it can also be made to reduce the thrust if too much has been previously selected and the wind should then increase dangerously.

I claim:

1. A sailing craft having at least one upright rigid aerofoil, means mounting said aerofoil for free rotation about an upright axis, a tail vane on the rotating aerofoil and control means for controlling the angular position of the tail vane with respect to said rigid aerofoil, said control means including first and second control levers for use respectively on port and starboard tacks, mechanical means interconnecting the levers so that moving one in one direction causes the other to move in the opposite direction and means operatively connecting the tail vane to said levers.

2. A sailing craft as claimed in claim **1** wherein the tail vane is aft of the main aerofoils and wherein the levers are arranged so that the first (for use on the port tack), when moved forward, causes the tail vane to move anticlockwise as seen from above and the second, when moved forward, causes the tail vane to move clockwise as seen from above.

3. A sailing craft as claimed in claim **1** wherein said control means includes a linkage with an axial movable member on the sail pivot axis, said linkage including a swivel permitting rotation of the output of the linkage onto the sail system, independent of the fixed position of the input onto the linkage from said levers.

4. A sailing craft with a rigid aerofoil assembly, means mounting said aerofoil assembly for rotation about an upright axis, a tail vane mounted on the assembly for rotation with respect thereto for controlling the angular position of the aerofoil assembly, and control means for the tail vane wherein the control means include an adjustable stop device limiting the angular movement of the tail vane with respect to said aerofoil assembly and means responsive to the wind strength operatively controlling said adjustable stop to reduce the range of movement as the wind strength increases.

5. A sailing craft with a rigid aerofoil assembly, means mounting said aerofoil assembly for rotation about an upright axis, a tail vane on the assembly for controlling the angular position of the aerofoil assembly, means mounting the tail vane for angular rotation with respect to said assembly, and control means for said tail vane, said control means including a control input and a linkage connecting the control input to the tail vane and further including adjustable means for adjusting the velocity ratio between the tail vane movement and control input and a wind strength responsive device operatively controlling said adjustable means.

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