July 23, 1968 T. H. LAUFER 3,393,747

CONTROLLERS FOR AIR CUSHION CRAFT

Filed April 18, 1967 3 Sheets-Sheet 1

Fig.1

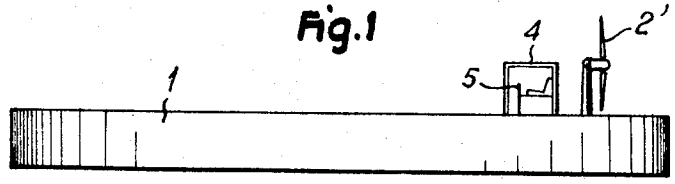


Fig.2

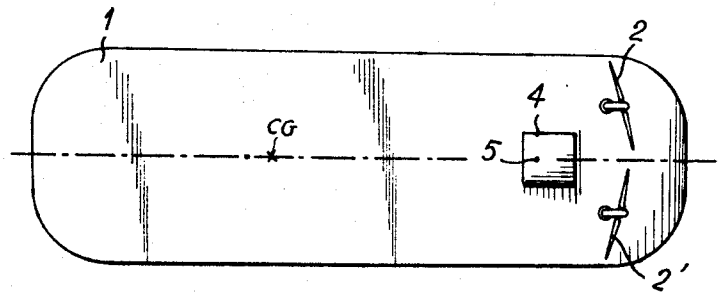


Fig.5

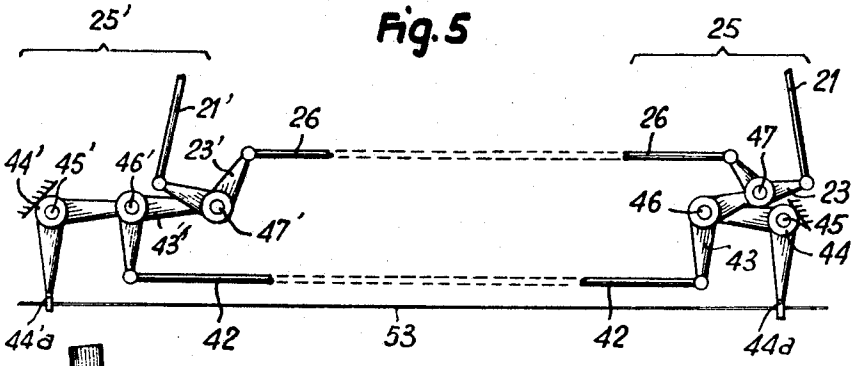


Fig.6a

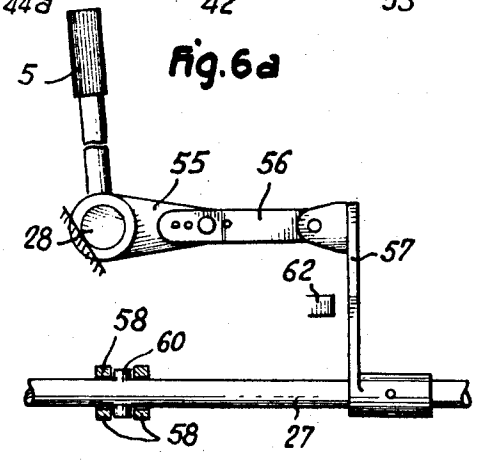
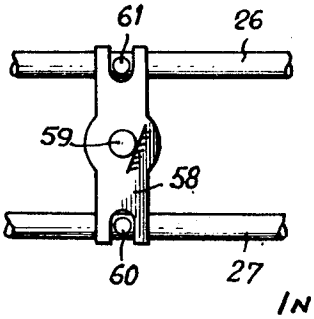


Fig.6b



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July 23, 1968 T. H. LAUFER 3,393,747

CONTROLLERS FOR AIR CUSHION CRAFT

Filed April 18, 1967 3 Sheets-Sheet 2

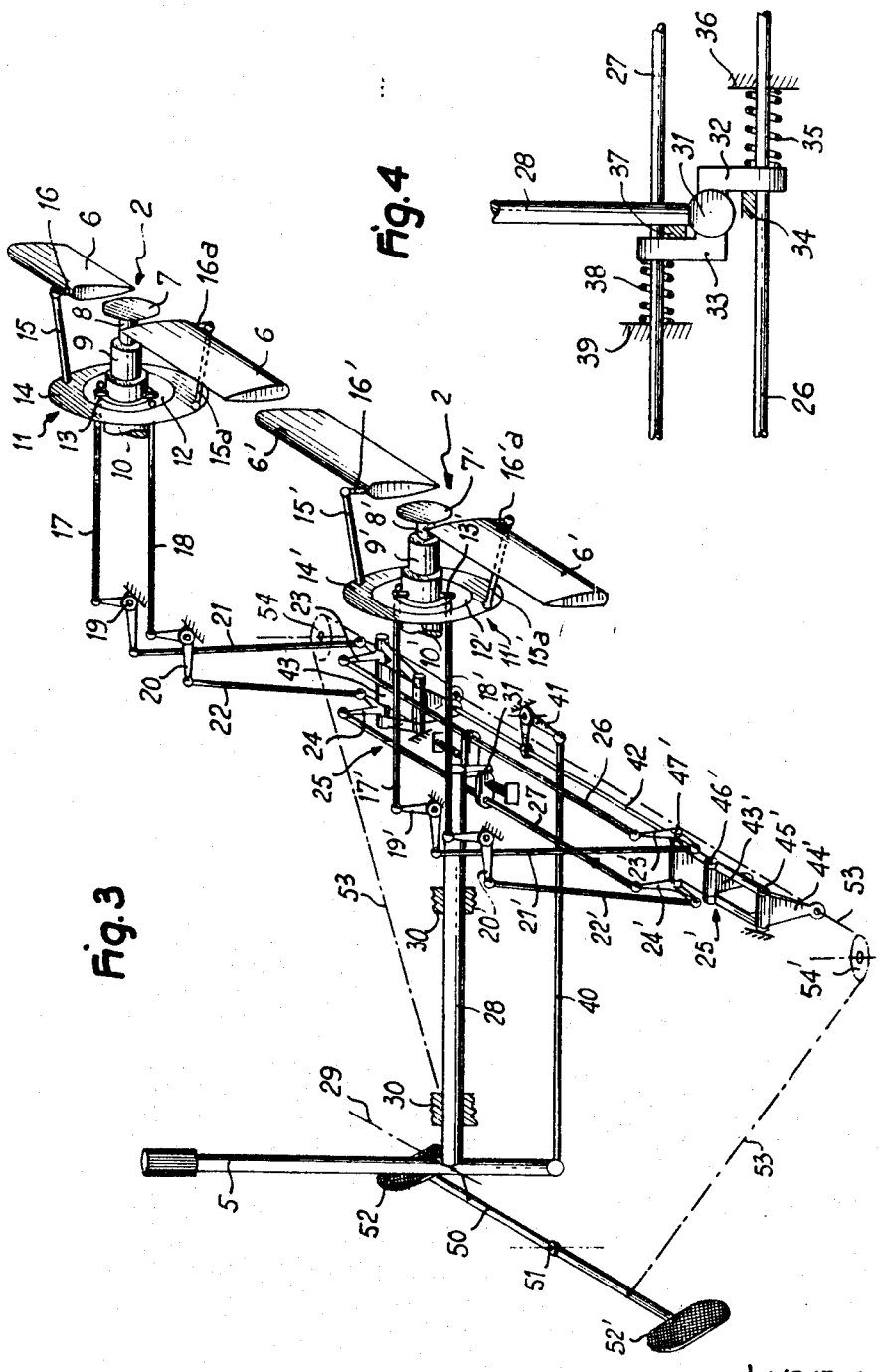


Fig. 3

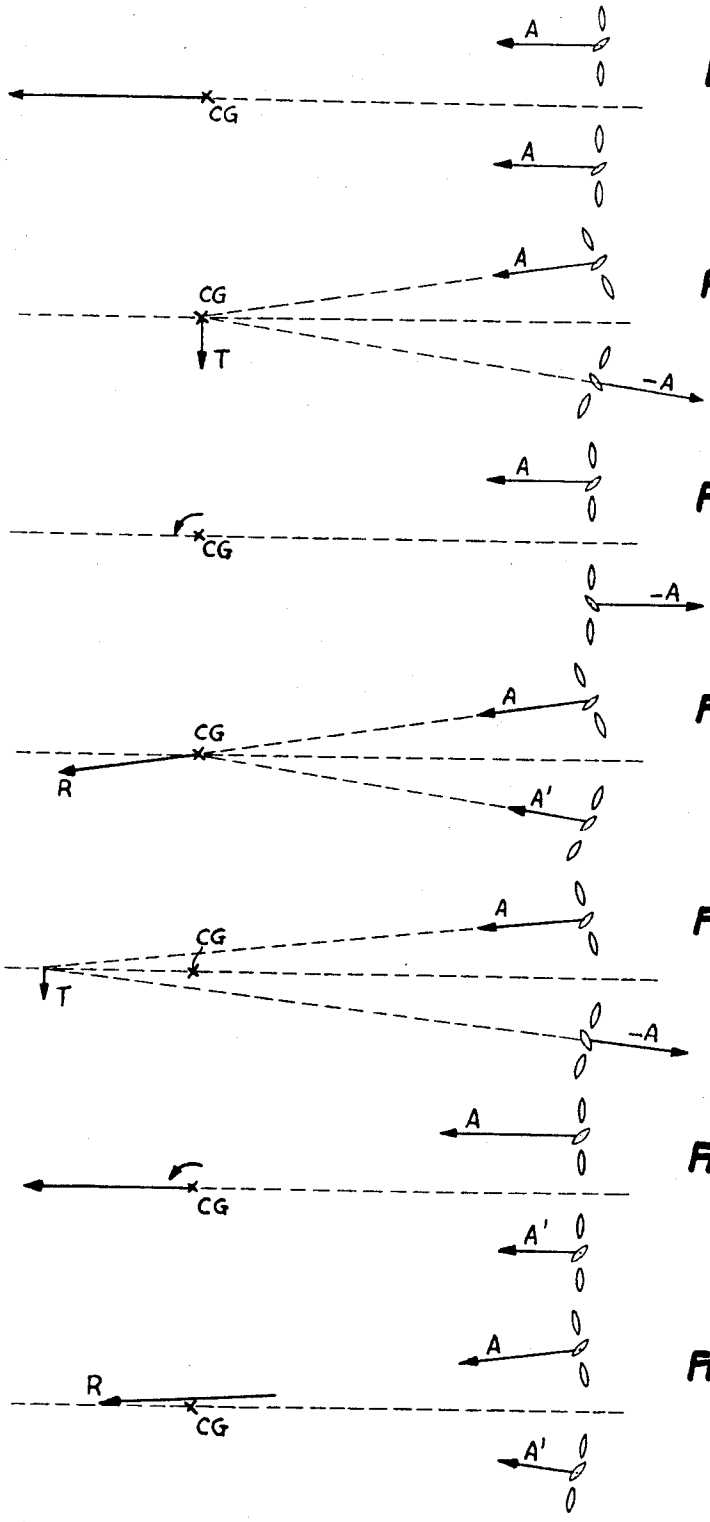
Fig. 4

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July 23, 1968 T. H. LAUFER 3,393,747

CONTROLLERS FOR AIR CUSHION CRAFT

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CONTROLLERS FOR AIR CUSHION CRAFT

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10 Claims. (Cl. 170—135.24)

ABSTRACT OF THE DISCLOSURE

Directional controllers for an air cushion craft driven by a pair of propellers, wherein all the various possible manoeuvres in a plane due to the various changes of the pitches of the propellers can be executed by means of two control elements only, namely a joystick and a rudder bar.

The present invention relates to directional controllers for air cushion craft driven by airscrews or propellers.

Preferably, such a craft is driven by two airscrews or propellers (or a number of pairs of airscrews or propellers) symmetrically placed with respect to the longitudinal plane of symmetry of the craft, and they are bodily adjustable for angular pitch whilst their blades are of variable pitch. The pilot has available three modes of controls: one for common changes in the blade pitch of the two propellers simultaneously; one for differential changes of blade pitch of the two propellers (i.e. an increase in blade pitch of one of the propellers and an equal reduction in blade pitch of the other); and one for changing the angular pitch of the axes of the two propellers together.

Given that a common change of blade pitch involves, for the two propellers, a change of thrust and eventually a reversal thereof; that a differential variation of blade pitch modifies the algebraic relationship between the thrusts delivered by the two propellers; and that a variation of angular pitch involves a variation in the direction of the thrusts delivered by the two propellers, it is clear that with these three types of control at his disposal the pilot can compound the thrusts in such a way as to obtain a resultant whose point of application, magnitude and sense can be adjusted at will, with or without the superimposition of a couple whose moment and sense can equally be modified at will. Specifically, all possible movements in a single plane can be effected.

It is an object of the present invention to achieve the above three separate modes of manoeuvre control by the use of only two control elements, such as a joystick or control stick and a rudder bar.

It is another object of the invention to provide a linkage which ensures that longitudinal displacement, or mutual angular inclination (or both), of the planes of rotation of the two propellers is combined with one of the other modes of control.

A further object of the invention is to provide that the linkage governing the manoeuvring of the craft is such that a change of angle of the axis of rotation of the two propellers (angular pitch) is made symmetrically with respect to the longitudinal plane of symmetry of the craft such that the point of intersection of the lines of thrust always lies in this plane.

According to a feature of the invention the controller for symmetrically adjusting the angular pitch is combined with the differential blade pitch controller in such a way that, for one given position of the single controller (which may be a control stick), the combination of thrusts gives a transverse resultant passing through the centre of gravity of the craft with zero couple.

In another embodiment, which may be more acceptable to the pilot, control of the angular pitch of the line of thrust is carried out independently by one of the controls, for example the control stick, whilst change of differential pitch is effected by the other controller, such as the rudder bar. In these conditions the pilot can cause the craft to traverse sideways without a swinging couple, by himself combining the change of angular pitch and the change of blade pitch in such a way as to cause the resultant of the thrusts to pass through the centre of gravity transversely without a turning moment.

Other features of the invention will appear in the course of the following description, given entirely by way of example only of possible ways of carrying the invention into effect with reference to the accompanying drawings wherein:

FIGURES 1 and 2 are schematic side elevation and plan views, respectively, of an air cushion craft;

FIGURE 3 is a perspective view of one form of linkage providing three modes of control;

FIGURE 4 is a plan view of a detail of FIGURE 3;

FIGURE 5 is an elevation showing one mechanism for compounding a plurality of control actions;

FIGURES 6*a* and 6*b* are fragmentary elevation and plan views respectively, showing an alternative embodiment, and

FIGURES 7*a*–7*g* are diagrams illustrating different kinds of manoeuvre which can be executed by controllers according to the present invention.

FIGURES 1 and 2 show schematically an air cushion craft having a hull **1** and two airscrews or propellers **2**, **2'** mounted at the stern symmetrically with respect to the longitudinal plane of symmetry containing the centre of gravity CG. The pilot's cabin is shown diagrammatically at **4** with the joystick or control stick **5** having two degrees of freedom of control movement.

FIGURE 3 shows one practical form of the controls for enabling the following separate functions to be performed by two control elements, shown as a joystick and a rudder bar:

- a change in the general pitch of the two propellers at the same time;
- a change of the planes of rotation of the two propellers simultaneously and symmetrically combined with a change of differential pitch;
- a change of differential pitch.

In this example, each of the propellers **2** or **2'** has two blades **6** or **6'** mounted on a hub **7** or **7'**. The shaft **8** or **8'** of the hub is carried in a mandrel **9** or **9'** on which a sleeve **10** or **10'** is slidable. Each sleeve carries a pitch unit generally indicated at **11** or **11'** and whose non-rotary component **12** or **12'** is pivoted by trunnions **13** or **13'** on a vertical axis. The non-rotary component is thus linked to the sleeve **10** or **10'** for axial displacement, but can assume an angle to the sleeve. The drive for the thrust ring has not been illustrated but can readily be deduced from the techniques which are well-known in helicopters.

The rotary component **14** or **14'** of the pitch unit **11** or **11'** bears against thrust rods **15**, **15***a*, **15'**, **15'***a* which are connected to the blades **6** or **6'** by respective lugs **16**, **16***a*, **16'** **16'***a*. To the non-rotary component **12** or **12'** of each pitch unit are articulated, at diametrically opposite points pitch control rods **17**, **18**, **17'**, **18'** respectively for transmitting to the pitch units the necessary input pitch signals. The pitch control rods are pinned at their other ends to one arm of a respective bell crank **19**, **20**, **19'**, **20'**. To the other arm of each of these bell-cranks is pinned a respective rod **21**, **22**, **21'**, **22'** whose other ends are each pinned to a respective lower bell-crank lever **23**, **24**, **23'**, **24'** forming, respectively, pairs of pitch output signal components of two motion compounding

mechanisms referenced generally **25** and **25'**. The bell-cranks **23**, **24** are independently journally on a common fulcrum pin **47** and the bell-cranks **23'**, **24'** are independently journalled on a common fulcrum pin **47'**. The other arms of the lower bell-cranks are interlinked in pairs **23**, **23'** and **24**, **24'** by two horizontal tie rods **26**, **27** normal to the plane of symmetry, and each constituting one of the pitch input signal elements of the compounding mechanisms.

The control stick **5** is coupled to a shaft **28** in the plane of symmetry by a coupling which permits relative rotation about an axis **29**. The shaft **28** is carried in bearings **30** for rotation about its longitudinal axis. The end of the shaft remote from the coupling carries a lever **31** which can abut on one side on an arm **32** connected to the horizontal tie-rod **26** and on the other side on an arm **33** connected to the horizontal tie-rod **27**. As shown in greater detail in FIGURE 4, the arm **32** is urged against a stop **34** by a spring having a fixed abutment **36**, whilst the arm **33** is biased against a stop **37** by a spring **38** having a fixed abutment **39**.

The control stick **5** extends beyond the coupling with the shaft **28**, and is articulated at its lower end to a linkage comprising a rod **40** which operates a bell-crank lever **41** pivoted on a vertical axis. The other arm of this bell-crank is coupled to a lower horizontal rod **42** parallel to the rods **26**, **27**, and constituting another pitch input signal element of the compounding mechanisms. The rod **42** is articulated at each end to one of the arms of a bell-crank **43**, **43'** forming an input component of the respective compounding mechanism **25**, **25'**.

As shown more clearly in FIGURE 5, the motion compounding mechanism **25** consists of an input bell-crank lever **44** pivoted on a fixed axis **45**. The end of one of its arms carries a pivot pin **46** for another input bell-crank lever **43**, one of whose arms is articulated to the lower horizontal rod **42** whilst the other arm carries a common pivot pin **47** for the output bell-crank levers **23**, **24** (see FIGURE 3). The compounding mechanism **25'** similarly consists of an input bell-crank lever **44'** pivoted on a fixed axis **45'**. One of the arms of the bell-crank **44'** carries a fulcrum **46'** for the input bell-crank lever **43'**, one of whose arms is pinned to the rod **42** whilst the other arm carries a common fulcrum pin **47'** for the output bell-crank levers **23'**, **24'** (see FIG. 3). It is important to note that the relative attitude of the input bell-crank **43'** in the compounding mechanism **25'** is reversed compared with the relative attitude of the input bell-crank **43** in the compounding mechanism **25**.

The second control element for the pilot is a rudder bar **50** pivoted on a axis **51** and controlled by two pedals **52**, **52'**. To the rudder bar are anchored the two ends of a cable **53** which passes over conveniently placed guide pulleys **54**, **54'**. This cable is attached to the free arms **44***a* of the input bell-crank **44** in the compounding mechanism **25** and **44'***a* of the input bell-crank **44'** in the compounding mechanism **25'**.

The two control elements **5** and **50** can be used to produce separately the three modes of change of pitch referred to above.

To effect only a common change of blade pitch of the two propellers **2**, **2'** it is only necessary to pull or push the control stick **5**. Thus, movement of the stick forwards, for example, results in a pivotal movement about the axis **29** such that, by means of the linkage **40**, **41** the lower horizontal rod **42** moves to the left. This causes the bell-cranks **43**, **43'** in the two compounding mechanisms **25**, **25'** to turn. By reason of the reversal of the relative attitudes of these bell-cranks, both pivots **47**, **47'** move downwards, and the four rods **21**, **22**. **21'**, **22'** also move down to cause, through the bell-cranks **19**, **20**, **19'**, **20'**, a forward longitudinal displacement of the four rods **17**, **18**, **17'**, **18'** attached to the non-rotary components of the pitch units **11**, **11'**. The latter thus slide along the mandrels **9**, **9'**. This results in a common increase in blade pitch. Conversely, backward movement of the stick **5** produces a reduction in pitch.

To produce only a differential change of pitch of the two propellers **2**, **2'**, it is only necessary to operate the rudder bar **50** by pressing on one or other pedal **52**, **52'**. For example, movement of the left pedal **52'** produces, through the cable **53**, a rotation of the bell-cranks **44**, **44'** in the compounding mechanisms **25**, **25'**. This rotation of the bell-cranks on their fixed pivots **45**, **45'** causes on the one hand a raising of the fulcrum **46** of the bell-crank **43** and on the other hand a lowering of the fulcrum **46'** of the bell-crank **43'**. Consequently, since the bell-crank **43** is coupled to the rod **42**, it pivots and lowers the assembly of the bell-crank **23** and the rods **21** and **22**, whilst the bell-crank **43'** pivots to raise the assembly of the bell-crank **23'** and the rods **21'** and **22'**. This results in forward longitudinal displacement of the rods **17** and **18**, giving an increase in blade pitch of the propeller **2** while the rods **17'** and **18'** move backwards and cause a reduction in the blade pitch of the propeller **2'**.

Conversely, depression of the right pedal **52** produces the opposite differential change in blade pitch.

To produce a simultaneous symmetrical angular swing of the propellers (change of angular pitch) combined with a differential change of blade pitch, it is only necessary to swing the stick **5** to the left or right. This produces a corresponding rotation of the shaft **28**. For example, if the stick is swung to the left, the lever **31** carried on the shaft **28** pushes the arm **32** against the spring **35**, and this moves the rod **26** to the right in FIGURE 4. At the same time, the rod **27** remains stationary because the arm **33** is held against the stop **37**. Axial displacement of the rod **26** to the right causes an angular movement of the bell-cranks **23**, **23'** and hence a downward travel of the rod **21** and an upward travel of the rod **21'**. As a result of the opposed rotations of the bell-cranks **19**, **19'**, the rod **17** moves forward and the rod **17'** moves aft. Since the rods **18**, **18'** remain stationary, the axes of the thrust rings **14**, **14'** deflect towards the centre of gravity of the craft; or more generally, the axes of the thrust rings deflect so as to intersect in the longitudinal plane of symmetry. This deflection is combined with an axial movement which, for the ring **14**, is forward and thus increases the blade pitch of the propeller **2**. By contrast, the axial movement of the ring **14'** is rearwards and causes a reduction in the blade pitch of the propeller **2'**. Specifically, movement of the stick **5** to the left or right simultaneously modifies the angular pitch of the two propellers and their differential pitch, the sense of the differential pitch depending on the direction of inclination of the stick **5**.

The controls which have just been described enable a craft to make all the movements possible in one plane. The possible variations are shown schematically in FIGURES *7a*–*7g*.

To make a craft move directly ahead or astern, it is only necessary to push or pull the stick **5** since in this case the two thrusts of the propellers are equal and parallel, their blade pitches being equal and as large as necessary. There is no lateral thrust, and no couple is exerted on the craft (see FIGURE *7a*).

To make the craft move sideways it is necessary to move the stick **5** to the left or right according to the desired direction. It has been shown that this manoeuvre involves on the one hand changing the angle between the axes of the two propellers (angular pitch), and on the other hand adjusting the differential pitch. For a particular position of the stick **5** the resultant of the forces exerted by the two propellers passes through the centre of gravity CG, and provides a lateral thrust T without any turning moment (see FIGURE *7b*).

To produce a swinging motion about the centre of gravity—i.e. without linear motion ahead or sideways—it is only necessary to create a simple couple M. This is achieved by control of the differential pitch, as has been

described above, by moving the rudder bar **50** through one or other of the pedals **52**, **52'** according to the desired direction of swing (see FIGURE 7*c*).

In addition to these simple movements obtained by a single operation of one of the control elements, it is possible to make compound movements when the pilot himself operates the controllers in combination.

For example, to make the craft move ahead (or astern) and sideways simultaneously, it is necessary to push (or pull) the stick **5** and at the same time to move it left or right. In this case, the result is to combine an angular pitch change of the two propellers and a differential blade pitch (lateral displacement of the stick) and to superimpose a common blade pitch control on the two propellers (forward or backward movement of the stick). For one particular lateral displacement of the stick, the resultant R of the forces passes through the centre of gravity CG so that no couple is generated (see FIGURE 7*d*).

Lateral traverse with swing on a greater or less radius is obtained by left or right displacement of the stick in the manner required for combining angular pitch of the propeller axes and differential pitch of their blades, the resultant being a force T displaced from the centre of gravity by a greater or less distance according to the magnitude of the angular pitch of the propellers. Preferably, change of angular pitch should be small so that the directions of the thrusts intersect at a point ahead of the centre of gravity (see FIG. 7*e*).

In order to make the craft veer or change its heading without lateral traverse, the stick **5** must be pushed (or pulled) at the same time as the rudder bar **50** is operated. These two operations effect the superimposition of a differential pitch of the two propellers onto the common pitch control such that the two thrusts are parallel in the same direction but unequal. These two thrusts have a resultant which passes through the centre of gravity and a moment M about it (see FIG. 7*f*).

Finally, to execute a general motion comprising veering and traverse on a large radius, the stick **5** must be moved sideways and pushed or pulled, and the rudder bar **50** must be operated. In these conditions, an angular pitch is superimposed on both differential and common pitch controls. The lines of the two thrusts intersect at a point lying in the plane of symmetry, and since they are equal and non-parallel they have a resultant R inclined to the longitudinal centre line of the craft (see FIGURE 7*g*).

As will be understood, various modifications in the practical embodiment described above can be made. In particular, it has been shown that with the linkage described, movement of the stick **5** to left or right produces simultaneously an inclination of the thrust rings **14**, **14'** and an increase in the blade pitch of one propeller accompanied by a reduction in blade pitch of the other—that is to say, a variation in differential blade pitches. Nevertheless, the linkage can be modified in such a way that pivotal movement of the stick **5** to left or right results only in a change of angle of the thrust rings **14**, **14'** without changing the differential blade pitch. The only modification which needs to be made is in the part shown in detail in FIGURE 4, and is illustrated in FIGURES 6*a* and 6*b*.

Referring first to FIGURE 6*a*, the lever **31**, the arms **32** and **33**, the stops **34** and **37** and the springs **35** and **38** of FIGURE 4 are omitted. In their place, the shaft **28** carries a lever **55** which operates, through a link **56**, a bracket **57** rigidly fixed on one of the rods **26** or **27**—as shown, the rod **27**—the choice depending on which sideways motion of the stick **5** produces an inclination of the thrust rings **14**, **14'** such as to cause the lines of the propeller thrusts to intersect in the plane of symmetry ahead of the centre of gravity. The position of the lever **55** is such that its longitudinal axis should be coincident with that of the link **56** when the stick **5** is in the mid position of its permissible lateral displacement. In addition, and as shown in FIGURE 6*b*, a lever **58** having forked ends is pivoted about a fixed vertical axis **59** lying between the two rods **26** and **27**. One of the forked ends of this lever cooperates with a cotter pin **60** carried by the rod **26** while the other forked end cooperates with a cotter pin **61** carried by the rod **27**.

When the stick **5** is moved sideways to left or right, the lever **55** on the shaft **28** swings and produces a movement of the bracket **57** on the horizontal rod **27** to the left. Simultaneously, through the reversal effected by the forked lever **58** pivoting about its axis **59**, the rod **26** moves lengthwise to the right.

Referring now to FIGURE 3, it is clear that displacement of the rod **27** to the left produces an aft longitudinal displacement of the rod **18** and a forward displacement of the rod **18'**. At the same time, displacement of the horizontal rod **26** to the right produces forward lengthwise movement of the rod **17** and aft movement of the rod **17'**. As a result, the thrust rings **14**, **14'** are symmetrically inclined, which changes the angular pitch without changing the blade pitch. A stop **62** (FIGURE 6*a*) limits the travel of the bracket **57** to avoid the controls becoming reversed.

The pilot can himself combine this change of angular pitch, obtained by lateral movement of the stick **5**, with a change of differential blade pitch by operating the pedals of the rudder bar **50**. This separation of the two controls may be more convenient because it allows more sensitivity in the movement of the control. Thus, to cause the craft to traverse sideways, the pilot can apportion the traverse—that is to say, vary the point of application of the lateral thrust T in the plane of symmetry—under control of lateral displacement of the stick whilst at the same time adjusting the magnitude of the traverse with the aid of the pedals.

As explained above, the various possible manoeuvers in one plane can all be executed easily.

The embodiments described are given solely by way of example, and numerous modifications of them are possible without departing from the scope of the present invention. In particular, the various necessary adjustments for some of the levers at least can be effected by making provision for the adjustment of their effective lengths. For example, FIGURE 6*a* shows provision for adjusting the position of the point of connection between the lever **55** and the link **56**. Similarly, the various embodiments can be completed by the introduction of parallel circular movement where the two thrust rings **14**, **14'** move in the same sense. In this case, a special element would be provided to allow this supplementary control—for example, a wheel on the stick **5** or a second stick.

Finally, the invention has been described specifically for the case of two propellers (or a number of pairs of propellers), since it is in these conditions that it achieves the greatest advantage. Nevertheless, if some of the movements can be dispensed with—especially lateral traverse—it is possible to apply the invention to the case of a single propeller with control of the angle of its axis of rotation and control of the blade pitch. It is then possible to combine with the propeller another control element such as a rudder to achieve movements as near as possible to those which can be achieved with two propellers.

I claim:

1. A directional control gear for an air cushion craft having a pair of propellers symmetrically disposed relative to the longitudinal plane of symmetry of the craft with variable pitch blades and adapted to be adjustable for angular pitch relative to the said plane of symmetry, including two pilot's control elements, means connected between said control elements and said propellers for effecting all of the following actions:

(i) variation of the blade pitch of both propellers in

the same direction and to the same extent simultaneously;

(ii) variation of the blade pitches of both said propellers in opposite directions and to the same extent simultaneously, and

(iii) variation of the angular pitch of both propellers simultaneously in opposite directions about a substantially vertical axis, the angles between the planes of propeller rotation and the longitudinal plane of symmetry of the craft always remaining equal, and means for causing said latter control action to be effected by one of said control elements in addition to another control action effected thereby.

2. A control gear according to claim 1 comprising a pitch control unit associated with each propeller for varying blade pitch and angular pitch; a respective motion compounding mechanism associated with each pitch control unit; two pitch input signal members interconnecting each pitch control unit with pitch output signal components of the respective motion compounding mechanism, and a plurality of input components in each compounding mechanism, and coupled to the pilot's control elements.

3. A control gear according to claim 2 wherein each motion compounding mechanism comprises a train of levers having a pair of coaxial independent output levers whose common fulcrum is carried on one end of an input lever whose other end is coupled to a pilot's control element.

4. A control gear according to claim 3 wherein the end of each output lever which is not connected to a respective pitch input signal member is connected to a pilot's control element.

5. A control gear according to claim 4 wherein each motion compounding mechanism has two input levers each having its one end coupled to a pilot's control element and its other end carrying a fulcrum for another lever in the train.

6. A control gear according to claim 5 comprising a first pilot's control element having two degrees of freedom of movement; one in each of two planes at right angles; a second pilot's control element having a single degree of freedom of movement; a first input lever pivoted on a fixed fulcrum and coupled to said second pilot's

control element, and a second input lever pivoted on one end of said first input lever and coupled to said first pilot's control element and responsive to movements in one plane.

7. A control gear according to claim 6 comprising a shaft rotatable by movements of said first pilot's control element in the other plane; a lost motion connection between said shaft and each of said output levers of each compounding mechanism, said lost motion connections being of opposite senses; and a direct connection between said first input lever in each compounding mechanism and said second pilot's control element.

8. A control gear according to claim 6 wherein the pairs of corresponding output levers in the two compounding mechanisms are interlinked for equal and opposite displacements and one pair is directly coupled to said first pilot's control element for actuation in response to movements of said element in the other plane.

9. A control gear according to claim 2 wherein each pitch control unit includes a slidable member; a non-rotary component pivotally mounted on said slidable member and coupled to said two pitch input signal members for angular displacement thereby about its pivot axis; and a rotary component supported on said non-rotary component for controlling the pitch of the blades.

10. A control gear according to claim 9 wherein the compounding mechanisms have counterpart input members one of which in one mechanism is inverted with respect to its counterpart in the other mechanism so that a single angular pitch control movement of a pilot's control element produces equal but opposite angular deflections of the non-rotary components of the pitch control units.

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