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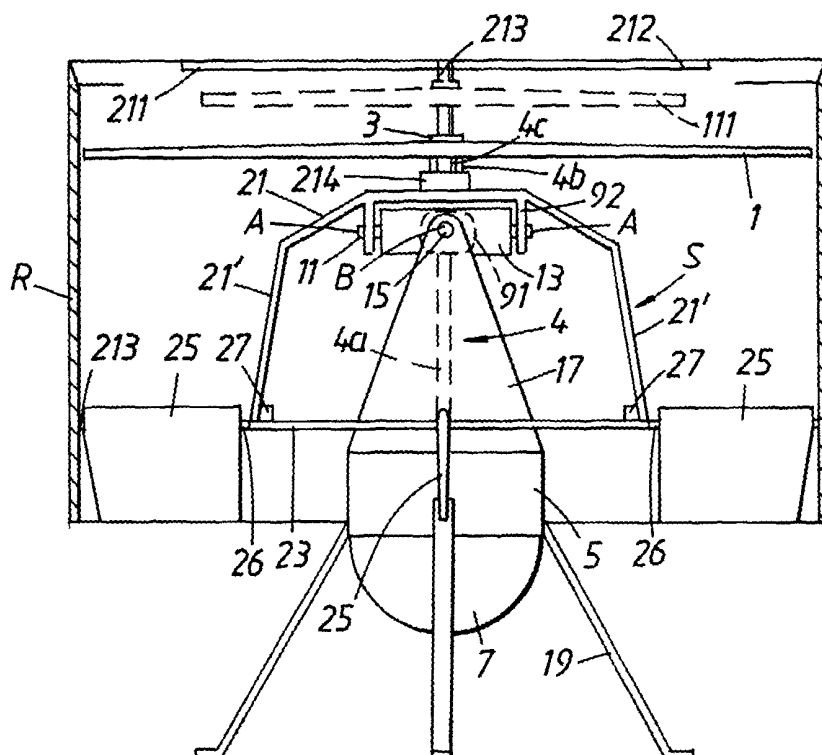
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(54) Title: UNPILOTED ROTOR-DRIVEN AIRCRAFT



(57) Abstract: An unpiloted rotor-driven aircraft comprising a drive unit (5) having a drive motor connected via a rotor shaft (4) to a rotor member (1) for generating a substantially downwardly directed air stream, a load carrier (7) arranged below the drive unit (5) and connected thereto, and a control means (S) the angular movement of which is independent in relation to the load carrier (7) and which comprises a support member (21) provided with adjustable rudders (25) arranged to be influenced by the air stream generated by the rudder member (1) in order to control the movement of the craft, wherein the rotor shaft (4) comprises a lower rotor shaft (4a) and an upper rotor shaft (4b), which rotor shafts (4a, 4b) are articulately joined to each other by a first joint member (91) that permits limited angular movement between the lower rotor shaft (4a) and the upper rotor shaft (4b).



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UNPILOTED ROTOR-DRIVEN AIRCRAFT

Technical field

The present invention relates to an unpiloted rotor-driven aircraft comprising a drive unit having a drive motor connected to a rotor member for generating a substantially downwardly directed air stream, a load carrier connected to the drive unit, and a control means for controlling the movement of the craft.

Background art

Unpiloted aircraft are being used to an increasing extent, primarily as platforms for reconnaissance, monitoring and scaling, and also as communication links, etc. in both civilian and military applications. The aircraft are provided with suitable payload in the form of sensors for the intended tasks and communication equipment for transmitting the sensor information to the buyers. Sensors must also exist to sense the flying state of the aircraft, which information is then used for autonomous control of the aircraft and to inform a ground-based monitoring centre via telemetry. Control instructions are sent from the monitoring centre to the aircraft for its non-autonomous control.

The use of unpiloted instead of piloted aircraft has the advantage of not having to risk the lives and health of air crews on dangerous assignments, and also offers much greater freedom in designing the aircraft to optimise its qualities without having to take the requirements of the crew into consideration. This freedom can be utilised to increase operation times and flying altitudes or to provide small, relatively simple aircraft. The design of these aircraft may differ quite substantially from equivalent piloted aircraft.

The development of unpiloted aircraft (Unmanned Aerial vehicles, UAV) has hitherto been dominated by military requirements. Three main types of UAV have been developed, namely UAV for high altitude and long operating times, UAV for medium altitude and medium distances and UAV for short distances and low flying altitudes. The present invention relates to UAV for the last main type. For such short-distance operations it is desirable first and foremost for the aircraft to take off and land vertically instead of being dependent on airfields located some distance away to which the aircraft may have to be transported.

Various types of known aircraft exist which are suitable for developing

UAV for short-distance operations. One usual type is rotor aircraft, the manned equivalent of which is the helicopter. Known UAVs exist which resemble helicopters. On the other hand UAVs exist which are totally unlike helicopters although the lifting force of the aircraft is still achieved with the aid of rotors. This also applies to aircraft in accordance with the present invention. It is particularly important when designing such aircraft that good properties are obtained during hovering, i.e. when the aircraft is kept still in the air. However, good hovering properties usually result in poorer high-speed properties.

Most helicopters now in use have a rotor with varying numbers of rotor blades. To counteract the torque and to control the helicopter when swerving, a tail rotor is usually used to achieve a controllable torque. However, the tail rotor has certain drawbacks such as consuming considerable power and requiring a rather complicated construction for the helicopter. The altitude, tilt and roll of a helicopter are controlled by turning the rotor blades about their longitudinal axis. The control mechanism for this consists of push rods that turn the rotor blades and whose positions are controlled by a "swash" plate around the rotor shaft. The location and orientation of the swash plate is in turn controlled by two control sticks in the pilot's cabin. These control mechanisms, too, are rather complicated and sensitive to dirt, particularly in small helicopters.

An unpowered rotor-driven aircraft is also known per se (PCT/SE99/00099), which is provided with a drive unit that drives a rotor directly via a rotor shaft. A load carrier is also connected to the drive unit via a Cardan joint so that the drive unit can be angularly displaced independently of the load carrier. However, this solution with a Cardan joint between the load carrier and the drive unit causes the centre of gravity of the aircraft to be located extremely high with loads corresponding to the mass of the drive unit. This in turn means that the take-off and landing properties are poorer than if the centre of gravity were to be located lower.

Object of the invention

The object of the present invention is to provide an unpowered aircraft that has a robust construction and excellent hovering properties, i.e. when the aircraft is substantially stationary in the air.

Another object of the invention is to provide an unpowered rotor-driven aircraft with better take-off and landing properties than previously known aircraft of

this type.

Brief description of the invention

These objects are achieved by means of aircraft described in the introduc-
5 tion that are characterized in that the drive unit is directly connected to the load
carrier and in that the rotor shaft, which transfers power between the drive unit
and the rotor member, is divided into a lower rotor shaft and an upper rotor shaft,
which rotor shafts are articulately joined to each other by a first joint member. Fur-
thermore, the control means of the aircraft is journalled about the upper rotor
10 shaft, the control member and rotor members constituting a first part of the aircraft
and the load carrier and drive unit constituting a second part of the aircraft. The
first and second parts are articulately connected together by joint means. Joint
means are thus required for the rotor shaft and joint means between the control
member and the load carrier/drive unit. The joint means are placed so that one
15 axis of rotation of each joint means perpendicular to the rotor shaft coincides with
some angular position of the rotor shaft.

The aircraft is thus divided into two parts movable in relation to each
other, which has the following advantages:

As opposed to a rigid connection between the two aircraft parts, which
20 would require considerably greater torque to achieve a given degree of turning of
the rotor disc, the joint member in accordance with the invention provides better
control efficiency.

The load carrier suspended by means of the joint member acquires a
naturally vertical orientation, which is an advantage if the load consists of recon-
25 naissance equipment (cameras or the like) which should operate from a stable
platform.

Another object of the invention is to provide a construction which, in rela-
tion to known technology, offers a simpler and more robust solution to controlling
the aircraft and does not require the rotor blades to be turned about their longitu-
30 dinal axes with the aid of swash plates or similar arrangements, and in which tail
rotors can be avoided for the required torque when swerving.

This latter object is achieved by the aircraft being provided with adjustable
rudder elements that are not rigidly connected to the drive unit and are arranged
to be influenced by the air stream generated by the rudder member.

This steering principle comprising rudder elements is not new and has been shown earlier. However, the results appear not to have been positive, probably because no suitable places could be found on a helicopter to place the rudder elements. Steering, namely, requires strong torque being achieved on the aircraft without the use of unreasonably large rudder surfaces. This presupposes
5 that the torque arms of the rudder elements are sufficiently long in relation to the centre of gravity of the aircraft, which in turn necessitates a design of the body of the aircraft completely different from that of a normal helicopter.

The rotor member preferably comprises a split rotor shaft and a number
10 of elongate rotor blades which are rigidly connected to the upper part of the rotor shaft so that the rotor blades are fixed, or in other words, cannot be turned about their longitudinal axes. Such fixed rotor blades permit simple and robust attachment to the rotor shaft. Increased security is also obtained that the rotor blades will not become detached. A rotor blade that has become detached can cause
15 considerable damage around it, which limits the use of rotor-driven aircraft in sensitive environments. Protection against detached rotor blades can be improved by surrounding the rotor tips with a ring. The ring is preferably designed to be axially extended to also cover the rudder elements.

One drawback with fixed rotor blades in a conventional helicopter is that
20 speed and wind-inducing rotor torque is transferred to the helicopter and causes undesirable dynamic stress. This was the reason for movable rotor blades being introduced at an early stage in helicopters.

The load carrier in the aircraft in accordance with the invention is isolated from the influence of such dynamic stress thanks to the Cardan suspending of the
25 load carrier.

Experience has shown that helicopters hovering at low altitude are sensitive to gusts of wind and it is therefore difficult to maintain the desired orientation and position. The reason for the wind gusts influencing the helicopter is primarily that they create forces that act on the rotor member. Horizontal gust thus create
30 horizontal forces on the rotor member which turn the helicopter and even move it sideways.

The same problem naturally exists with rotor UAVs, and complicates their use for reconnaissance, for instance. Thanks to the rudder arrangement as in the embodiment described above it is possible to reduce this type of influence due to

wind gusts. The horizontal forces caused by gusts assault the UAV in the disc plane of the rotor member, i.e. above the centre of gravity of the aircraft. Through suitable placing of the rudder elements, the horizontal forces on the rudder elements can be caused to assault the aircraft below its centre of gravity so that the aircraft is stabilised. The effect of these forces caused by wind gusts can thus be neutralised by a suitable choice of placing and size of the rudder elements. Alternatively, or in addition, a strap can be arranged around the rudder elements. The strap may also be used to attach bearings of the rudder elements and to protect the rudder elements.

One way of balancing the torque around the rotor shaft is to use two concentric, but counter-rotating rotor members. Examples of this can be found in Soviet helicopters and the UAV projects Sentinel (Canada) and Sprite (Great Britain). As far as is known conventional turning of the rotor blades is used in these examples. One drawback is that the gyro-stabilising effect of a simple rotor member is lost since the counter-rotation involves a counteracting gyro effect. On the other hand the forces of the two rotor members caused by wind gusts are added. It is therefore important to use the stabilising rudder construction described above for a counter-rotating arrangement with rudder steering.

The practical design of the control means of the aircraft depends, amongst other things, on the choice of rotor system. According to one design the altitude control is presumed to be by control of the rotor speed. However, the present invention offers an opportunity, with constant rotor speed, to control the lifting force by at least one rotor element, preferably all, comprising a first rudder half and a second rudder half, separable from each other at the lower edge by an angle of α where α may assume a value from 0° to 180° . This division of each rudder element requires each element to have two servos for turning the rudder elements about two axes. Furthermore, in combination with a ring surrounding the rudders and the rotor, this arrangement allows the lifting force to be minimised since, together, the rudders throttle the air flow through the ring. The number of servos may also be reduced to two for each rudder by fitting a mechanism at each rudder which, with a servo, simultaneously turns both the rudder halves.

Each rotor system generates a swerving torque whose magnitude is dependent, amongst other things, on the speed. In a counter-rotating rotor system, therefore, the swerving torque can be controlled by a suitable difference in speed

for the two rotor members. If individual speed control cannot be used, an alternative is to use control means with rudder elements. For a single rotor system, swerve control and balance of the rotor torque are achieved with the aid of rudder elements set at a suitable angle of incidence to achieve swerve torque.

5 The rudder elements are placed as far downstream of the rotor disc as is practically suitable so that the torque arms are as long as possible. Such a torque arm may consist of a boom or some other rigid, elongate structure with a bearing at one end for the shaft of the rudder element, and being attached by its other end to the drive unit. Two rudder elements, fitted in a cross arrangement, are normally
10 used for roll control and two for tilt control.

 Turning of the rudder elements is effected with the aid of servo-arrangements. The minimum number of servo-arrangements is two (for roll and tilt control, respectively). With four servo-arrangements (one per rudder element) the swerve control can be superimposed as above. Another one or two servos for each rudder
15 are required to separate the rudder halves.

 The effect of the rudder control will differ depending on if a counter-rotating rotor system is used or a single rotor system. The difference is due to a single rotor constituting a gyro, thus causing the control effect of the rudder torque to be different from that for a counter-rotating rotor system.

20

Brief description of the drawings

 The invention will now be described in more detail with the aid of embodiments by way of example and with reference to the accompanying drawings in which

- 25 Figure 1 shows schematically a view from the side of one embodiment of an unpiloted rotor-driven aircraft in accordance with the invention with a ring, in section,
 Figure 2 shows schematically a view from above of the aircraft shown in Figure 1, and
30 Figure 3 shows an end view of a rudder for an aircraft in accordance with the invention.

Description of the invention

 Figure 1 shows schematically the design in principle of an unpiloted rotor-

driven aircraft (UAV) in accordance with the invention.

The aircraft comprises two main parts, a drive unit 5 with a load carrier 7 carrying suitable equipment such as reconnaissance cameras and fuel tank, a rotor member 1, the rotor blades of which are rigidly fixed in a rotor hub 3, together
5 with a control means S. The drive unit 5 houses a drive motor and a reduction gear for rotary driving of the rotor member 1. The rotor member 1 has a rotor shaft 4, connected to the hub 3 and rotatably driven by the drive motor in the drive unit 5. The rotor shaft is also divided into a lower rotor shaft 4a and an upper rotor shaft 4b, which rotor shafts 4a, 4b are articulately joined to each other by a first
10 joint member 91 that permits limited angular movement between the lower rotor shaft 4a and the upper rotor shaft 4b.

The load carrier 7 is arranged substantially vertically below the drive unit 5 and is preferably rigidly connected thereto.

The control member S, rotatably journaled about the upper rotor shaft 4b,
15 is provided with a second joint member 92 in the form of a second Cardan joint, with axes A-A and B-B perpendicular to each other. The Cardan joints comprise bearing journals 11 that are connected to the drive unit 5 and from the axis A-A. A Cardan ring 13 is arranged on the bearing journals 11, allowing it to oscillate about the axis A-A. A bearing journal 15 protrudes from the Cardan ring 13 at right
20 angles to the axis A-A, on each side of the rotor member 1, and forms the axis B-B. An axle housing 17 is journaled about each journal bearing 15 and is rigidly fixed to the drive unit 5 and the load carrier 7 by some suitable means, not described in more detail here.

The entire aircraft is supported in rest position by an undercarriage, here
25 in the form of a plurality of legs 19 secured at the lower end of the load carrier.

Figure 1 also shows schematically the control member S used in accordance with the invention. The rotor member 1 is identified by the rotor hub 3 and the drive unit 5 joined thereto via the rotor shaft 4. A carrier member 21 is rotatably journaled about the rotor shaft 4, this carrier member curving downwardly in
30 shanks 21' on both sides of the shaft, towards the drive unit 5. The internal distance between the shanks of the carrier member is sufficient to permit full freedom of movement for the load carrier 7 and drive unit 5. A retainer ring 23 is rigidly fixed at the lower ends of the shanks 21', on which ring 23 four rudders 25 are rotatably mounted. Each rudder 25 narrows across its cross section. In an initial

setting the rudders 25 are vertically oriented with the thicker portions of the rudders 25 directed upwards towards the rotor blades and the narrower parts directed downwards. The rudders are connected, each to its own rudder shaft 26, the latter being turnable by servo-means 27 to give the desired influencing torque on the drive unit 5. As should be evident from the drawings, the rudders are arranged in the downwardly directed air stream (swept down) from the rotor member 1.

Figure 1 also shows that, in the embodiment illustrated, the aircraft is provided with an annular casing R which protects both the rotor member 1 and the rudders 25. The casing is fitted on the rotor shaft 4b via at least two stays 211, 212, and to the outer ends of the rudders via rudder pins 213. The stays 211, 212 are centrally connected to a stay bearing journal 213 pivotably journaled and axially fixed in a stay bearing in the rotor hub 3. In the embodiment shown the aircraft is also provided with a second counter-rotating rotor member 111 rigidly connected to a second upper rotor shaft 4c, which is in turn connected to the upper rotor shaft 4b via a reversing gear 214 with an ingoing shaft and two concentric, outgoing shafts in a counter-rotating rotor system to eliminate the gyro effect of only one rotor member. In embodiments with double rotor members, the upper rotor shafts 4b, 4c are concentric and the stay bearing situated in the second rotor member 111.

Figure 2 shows that a rudder space RU in which the rudders 25 operate, is formed between the casing R and the retainer ring 23. The Figure indicates possible outer positions of the rudders 25 when fully deflected in broken lines. However, these broken lines shall also be seen as the outermost positions for rudder parts shown in the alternative embodiment of the rudder shown in Figure 3. The control member S, with its carrier member 21 and shanks 21', is hidden beneath the rotor member 1 in Figure 2. The Figure also shows the axis B-B through the journal bearings 15 fitted in the Cardan ring 13. For the sake of clarity the drive unit and axle housing are shown in Figure 2.

Figure 3 shows an advantageous embodiment of rudder for an aircraft in accordance with the invention. Each rudder 25 consists of two rudder halves 251, 253 flexibly journaled about their joint 252. The rudder halves can be folded out from each other so that their tips are moved out until the halves are aligned with each other, i.e. form an angle where $\alpha = 180^\circ$. Furthermore, regardless of the value of the angle α the rudder halves can be jointly turned about the rudder shaft

26. The rudders can thus steer the aircraft while at the same time the lifting force is reduced when the rudder halves are separated, without the rotor speed having to be altered. This is extremely advantageous at take-off and landing.

In the embodiments shown the unpiloted aircraft is described as having a
5 flexible connection between the drive unit 5 and control member S in the form of a
Cardan joint. One skilled in the art will naturally realise that any suitable type of
joint means can be used to give the desired all-round mobility between the com-
ponents, provided the joint means has two degrees of freedom (roll and tilt) and
that it is resistant to turning so that the turning influence of the rudder on the car-
10 rier member 21 is transmitted to the drive unit 5 and the load carrier 7.

Similarly, the invention can be modified in many different ways within the
scope of the appended claims.

CLAIMS

1. An unpiloted rotor-driven aircraft comprising a drive unit (5) having a drive motor connected via a rotor shaft (4) to a rotor member (1) for generating a substantially downwardly directed air stream, a load carrier (7) arranged below the drive unit (5) and connected thereto, and a control means (S) the angular movement of which is independent in relation to the load carrier (7) and which comprises a support member (21) provided with adjustable rudder elements (25) arranged to be influenced by the air stream generated by the rudder member (1) in order to control the movement of the craft, **characterized** in that the rotor shaft (4) comprises a lower rotor shaft (4a) and an upper rotor shaft (4b), which rotor shafts (4a, 4b) are articulately joined to each other by a first joint member (91) that permits limited angular movement between the lower rotor shaft (4a) and the upper rotor shaft (4b).
2. An aircraft as claimed in claim 1, **characterized** in that the control means (S) is rotatably journalled about the upper rotor shaft (4b).
3. An aircraft as claimed in claim 2, **characterized** in that the first joint member (91) consists of a first Cardan joint.
4. An aircraft as claimed in any one of claims 2-3, **characterized** in that a second joint member (92) is rigidly connected to the support member (21).
5. An aircraft as claimed in claim 4, **characterized** in that the second joint member (92) consists of a second Cardan joint.
6. An aircraft as claimed in any one of claims 4-5, **characterized** in that the drive unit (5) is connected to the second joint member (92) for independent angular movement in relation to the support member (21).
7. An aircraft as claimed in any one of claims 4-6, **characterized** in that an axis of rotation in the second joint member (92) coincides with an axis of rotation in the first joint member (91) in any other angular position between the rotor shafts

(4a, 4b) than when the shafts are parallel.

8. An aircraft as claimed in any one of claims 1-7, **characterized** in that servo means (27) are arranged to control the angle of incidence of the rudder elements (25).

9. An aircraft as claimed in any one of claims 1-8, **characterized** in that at least one rudder element (25) comprises a first rudder half (251) and a second rudder half (253), separable from each other at the lower edge by an angle of α where α may assume a value from 0° to 180° .

10. An aircraft as claimed in claim 9, **characterized** in that servo means (27) are arranged partly to control the angle of incidence of the rudders (25) and partly to control the angle of the rudder halves (251, 253) in relation to each other.

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11. An aircraft as claimed in any one of claims 1-10, **characterized** in that both the rotor member (1) and the rudders (25) are surrounded by an annular casing (R) which is connected to the support member (21).

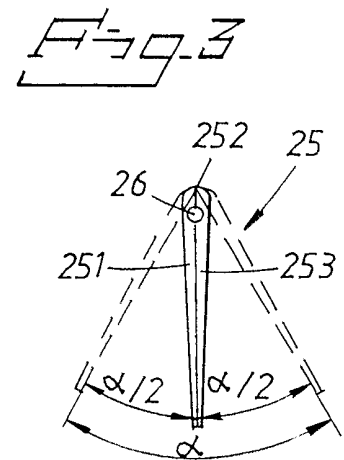
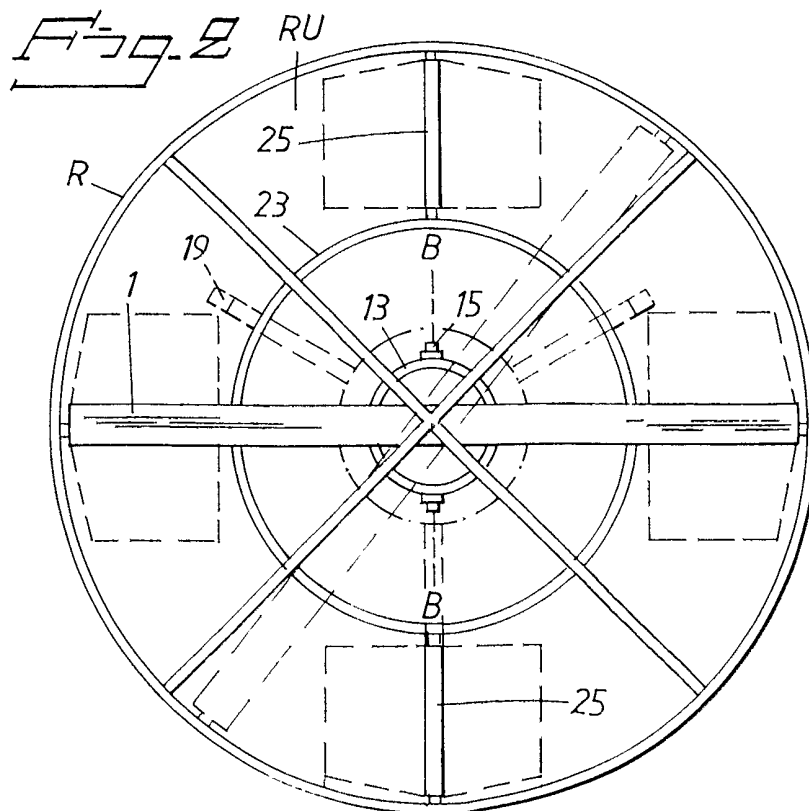
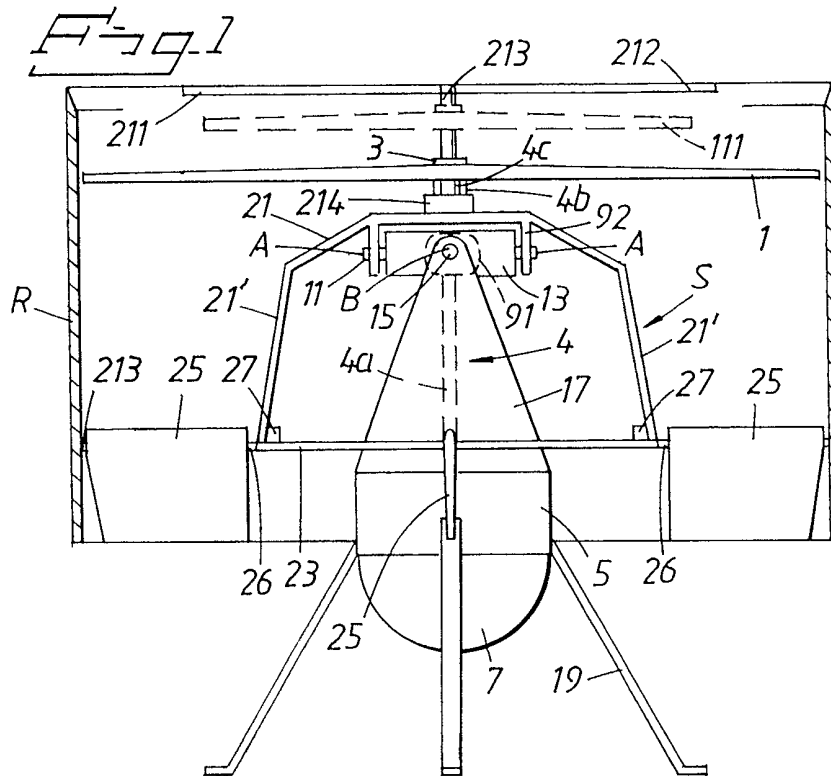
12. An aircraft as claimed in claim 11, **characterized** in that the rudders (25) are designed so that 20-60% of the axially projected area between a retainer ring (23) connected to the support member (21), and the casing (R) coincides with the axially projected area of the rudder halves (251, 253) when the rudder halves are at an angle of 180° .

25

13. An aircraft as claimed in any one of claims 1-12, **characterized** in that a counter-rotating second rotor member (111) is arranged to act in a plane parallel with the rotor member (1), the second rotor member being driven by the drive motor of the drive unit (5) via a second upper rotor shaft (4c) arranged concentrically with the upper rotor shaft (4b), which upper rotor shafts (4b, 4c) are connected to each other via a reversing gear (214) and to the lower rotor shaft (4a) via the first joint member (91).

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INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER

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B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, EPODOC, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 9938769 A1 (AVIA ADVISER HB), 5 August 1999 (05.08.99) --	1-13
A	FR 1604722 B1 (DURAND FRANCOIS), 3 March 1972 (03.03.72) --	1-13
A	WO 0134466 A1 (DEPOSANT ET), 17 May 2001 (17.05.01) -- -----	1-13



Further documents are listed in the continuation of Box C.



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Information on patent family members

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Patent document cited in search report			Publication date	Patent family member(s)		Publication date
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