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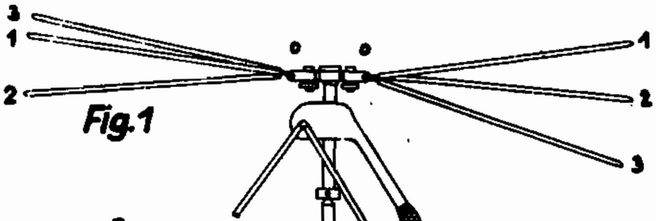

Fig.1

Fig.2

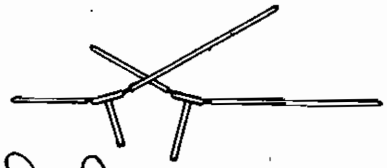

Fig.3

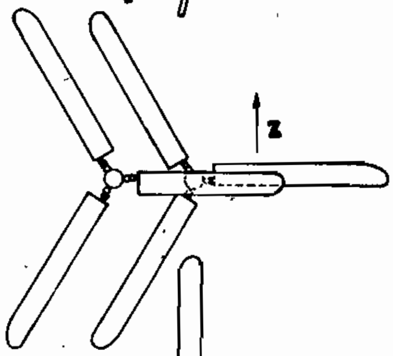

Fig.4

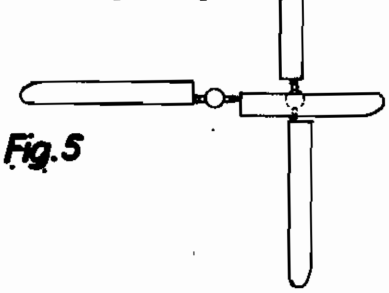

Fig.5

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Fig.6

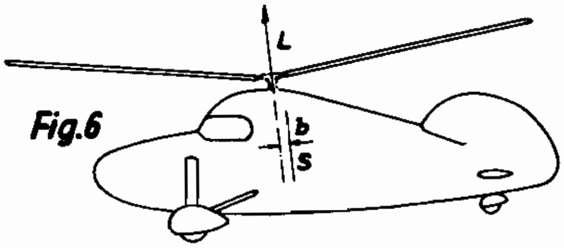

Fig.7

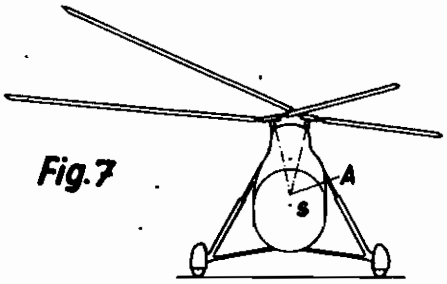

Fig.8

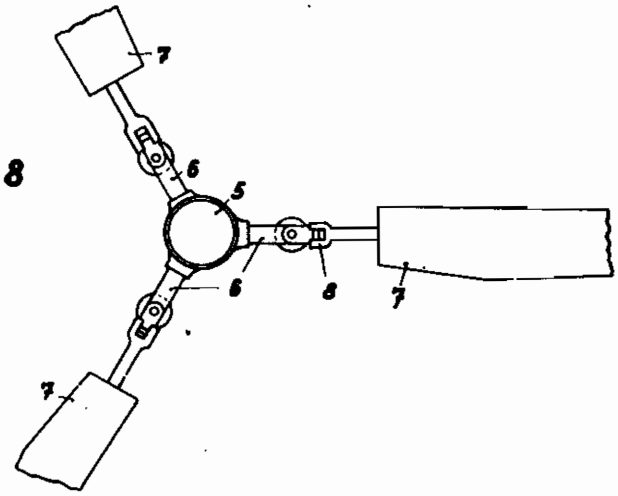

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Fig.9

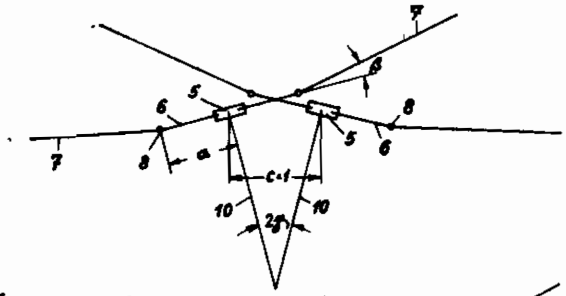

Fig.10

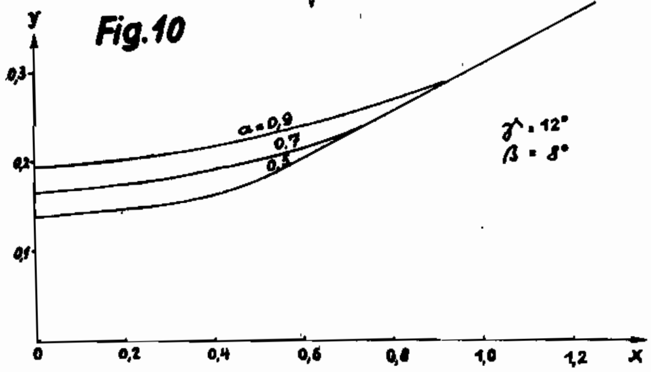

Fig.11

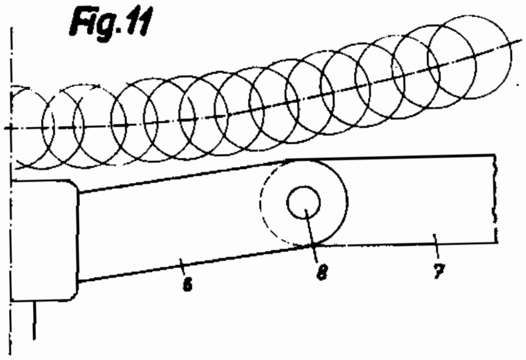

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Fig. 12

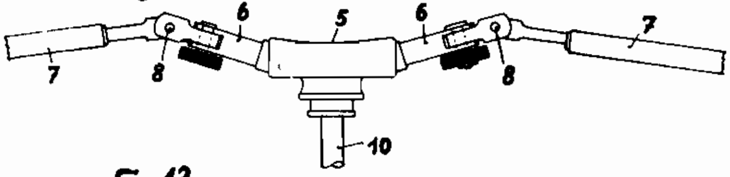

Fig. 13

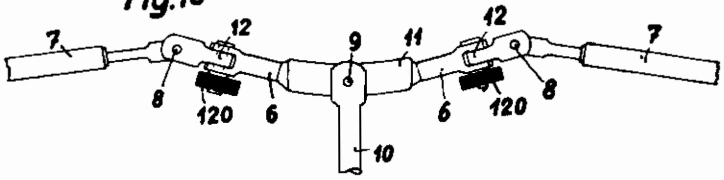

Fig. 14

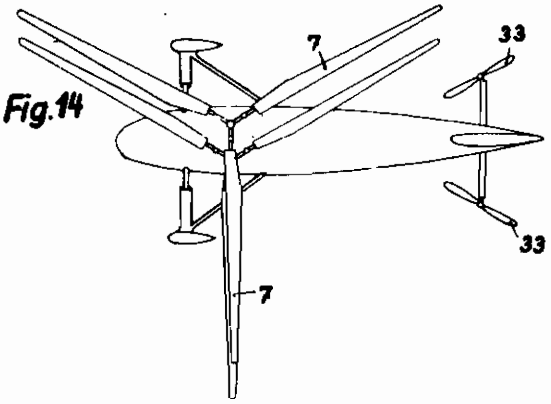

Fig. 15

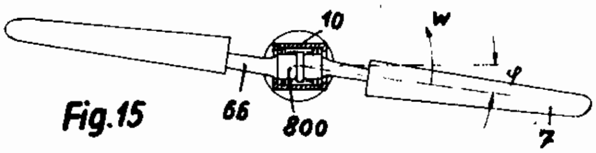

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Fig. 16

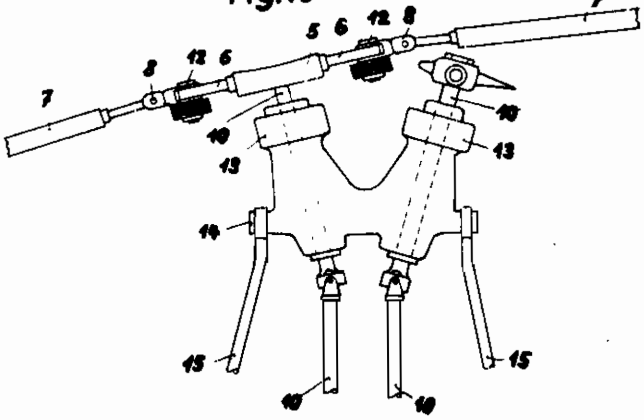

Fig. 17

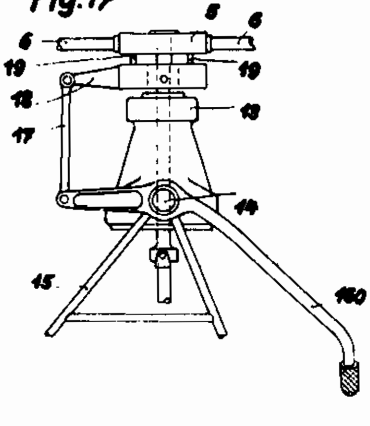

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Fig.18

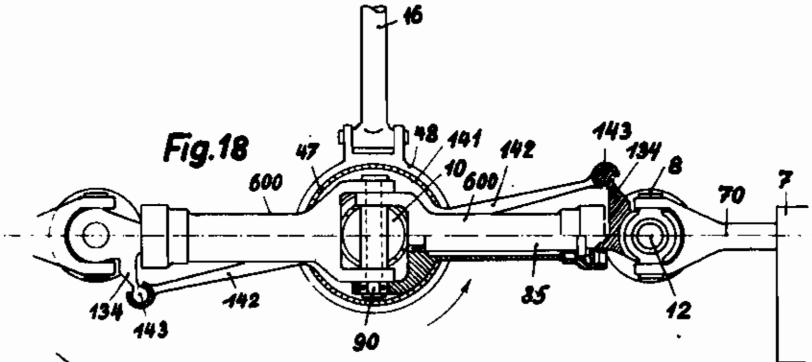


Fig.19

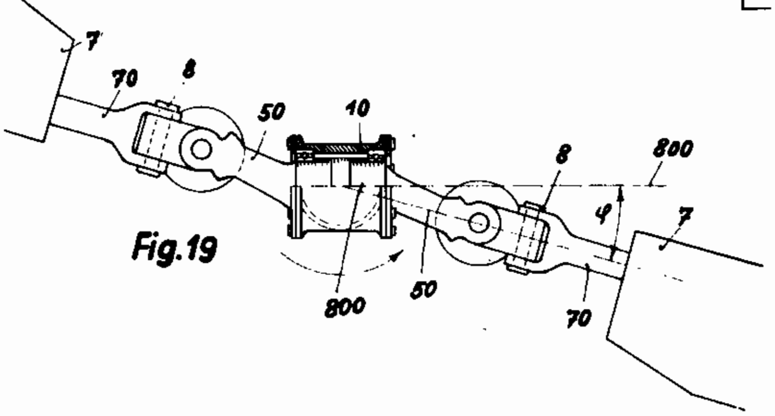
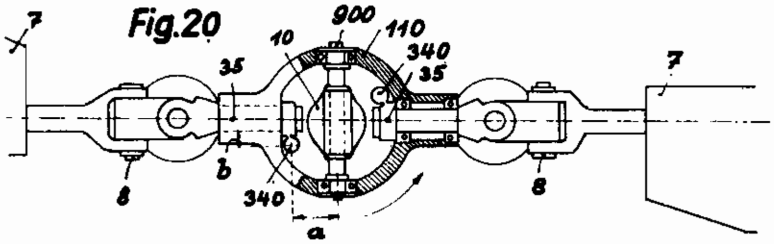


Fig.20



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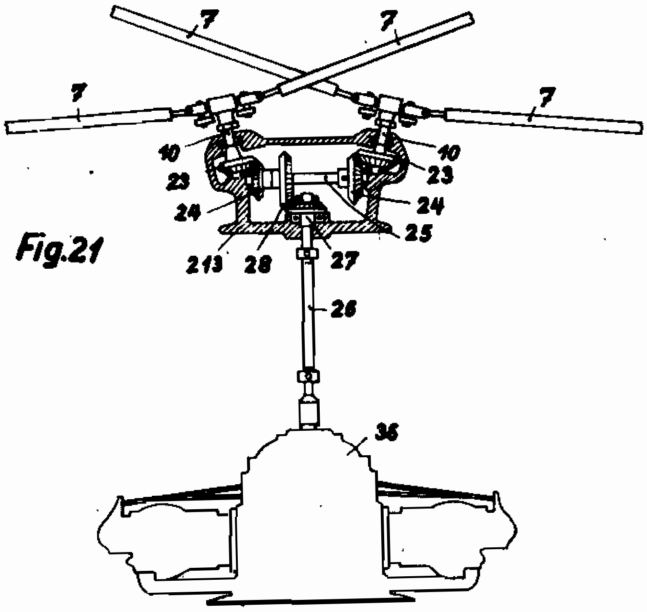
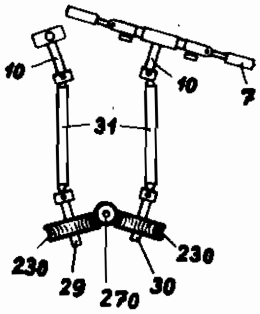


Fig.21

Fig.22


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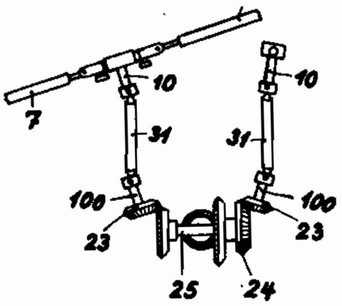

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Fig.24

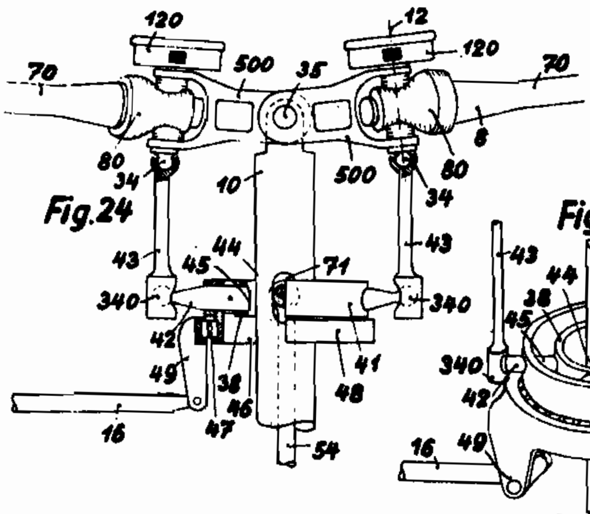


Fig.25

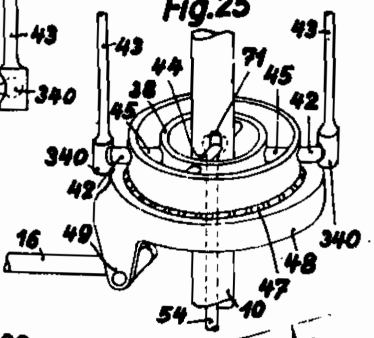


Fig.26

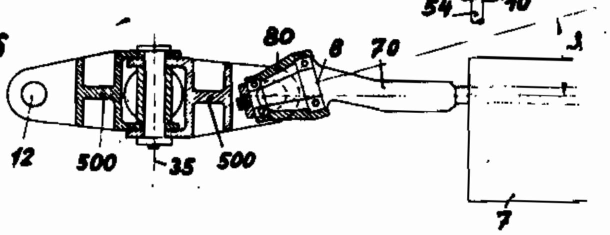
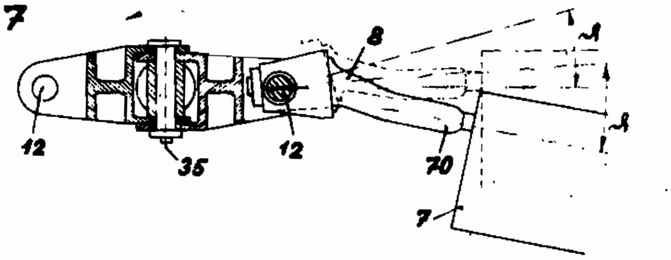


Fig.27



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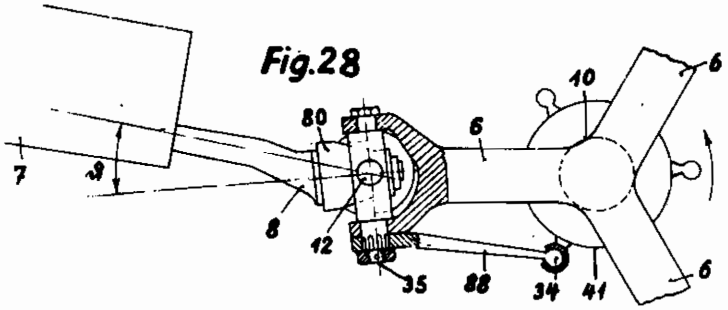

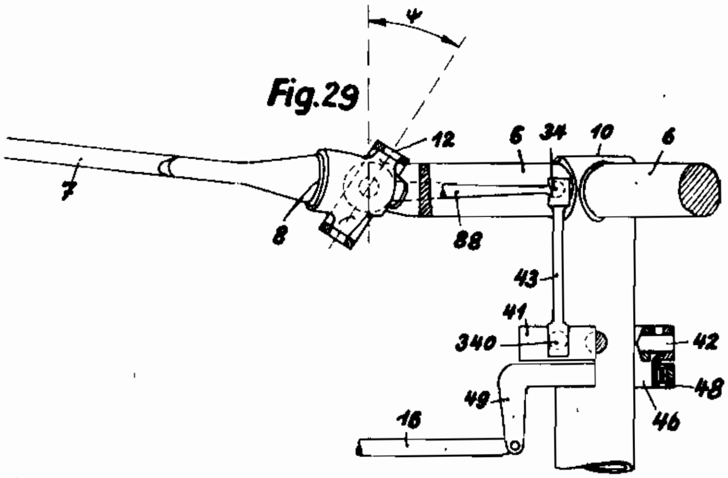

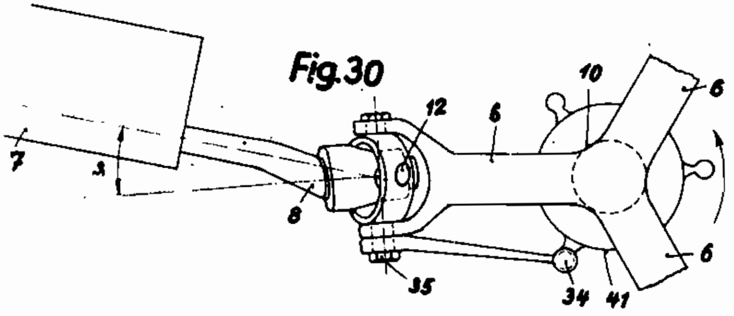

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Fig.31

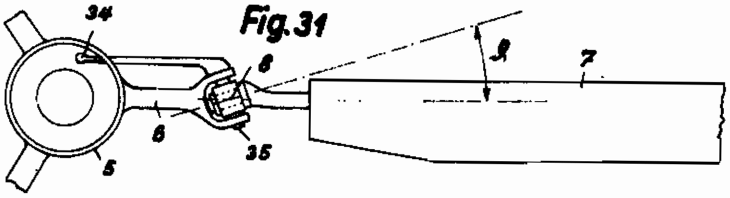

Fig.32

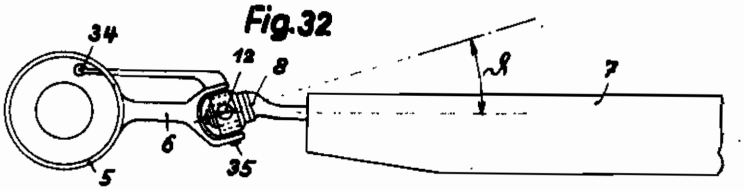

Fig.33

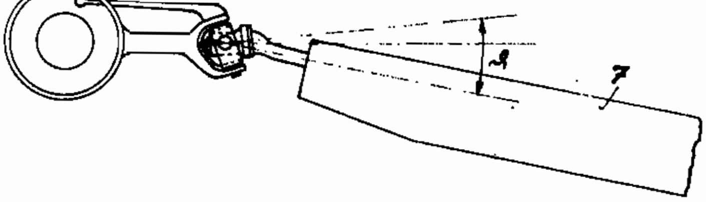

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Fig. 34

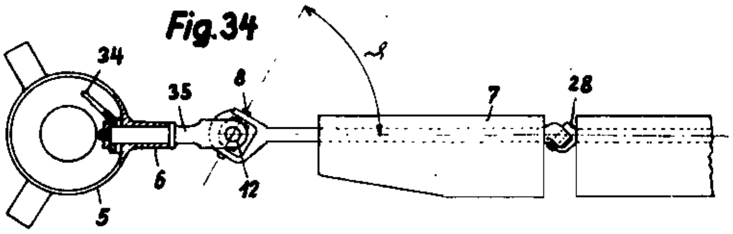

Fig. 35

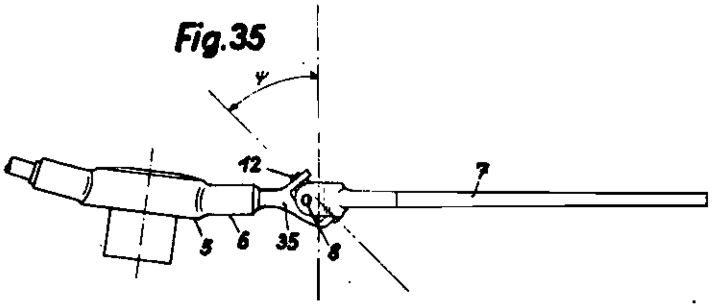

Fig. 36

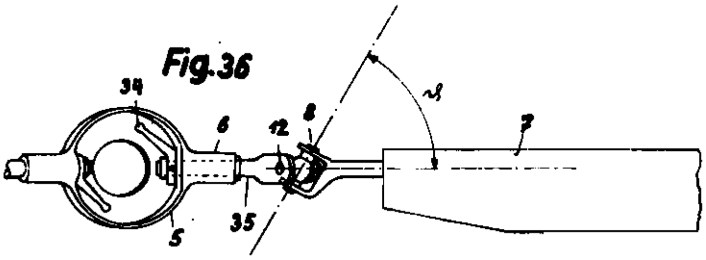

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Fig.37

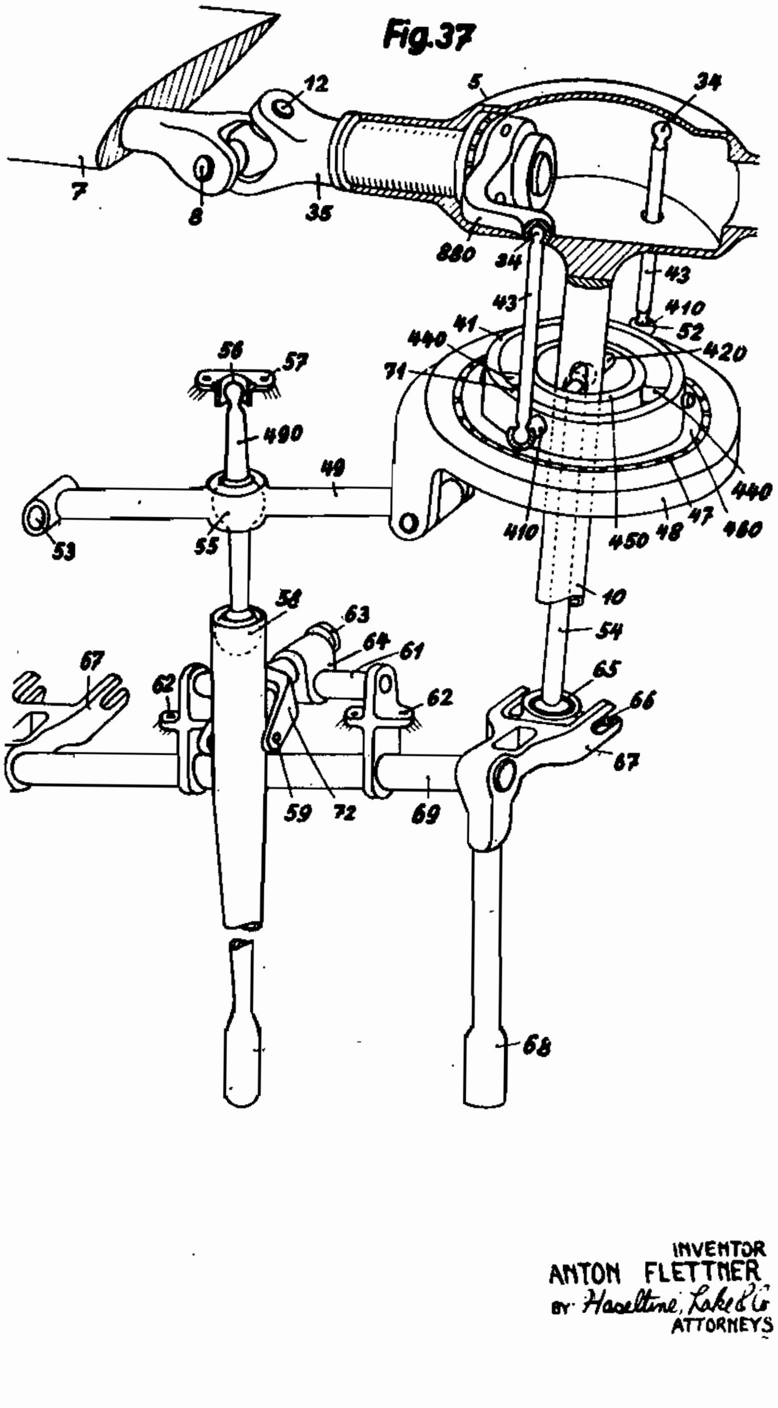

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Fig.38

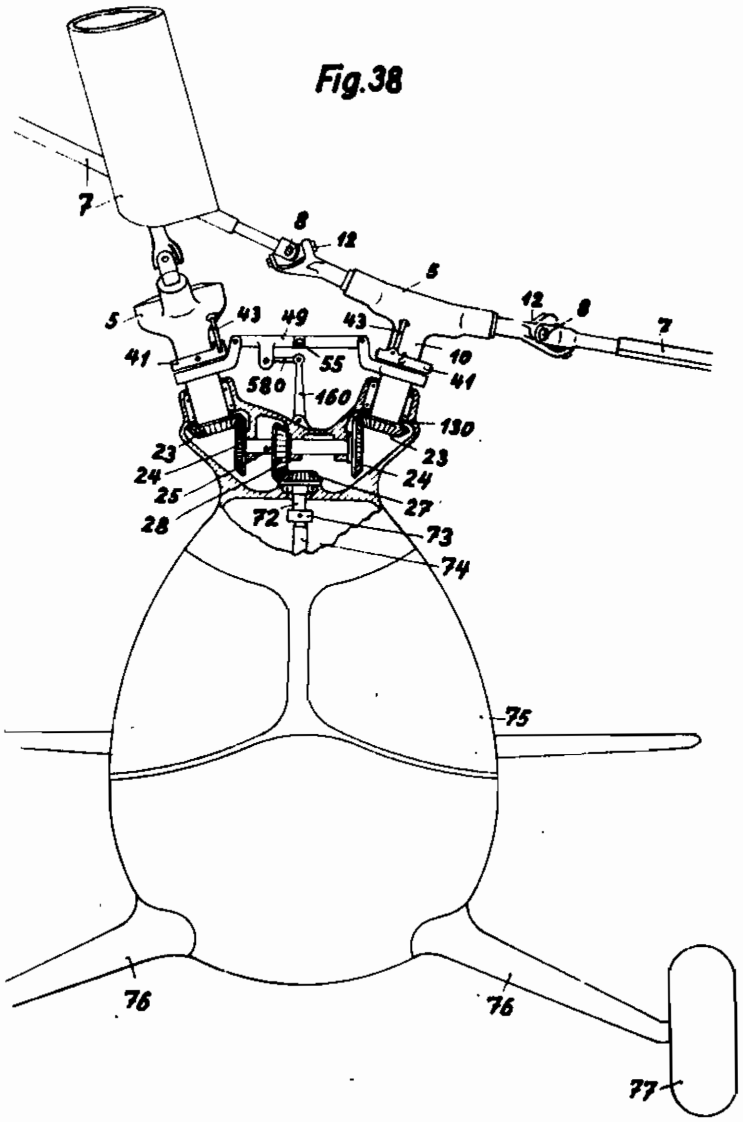

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Fig.39

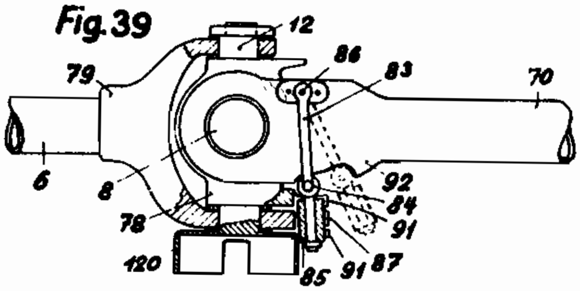

Fig.40

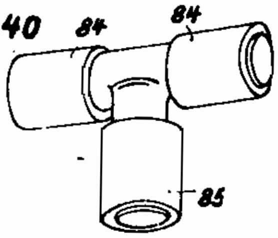

Fig.41

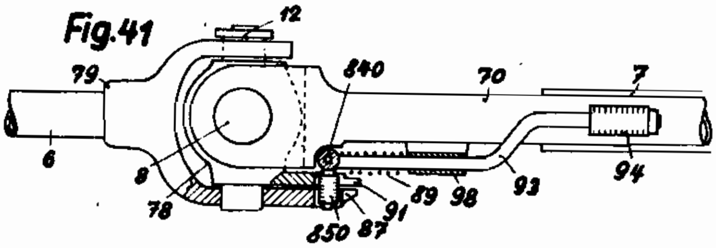

Fig.42

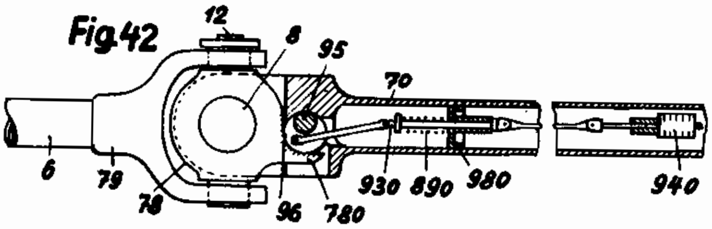

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Fig.43

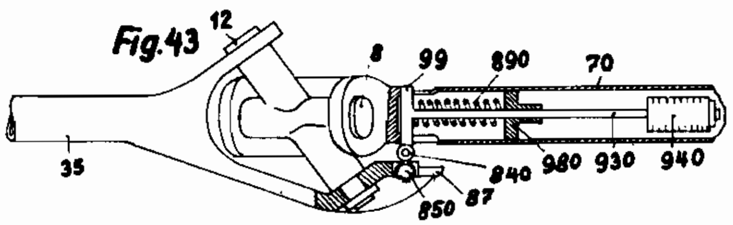


Fig.44

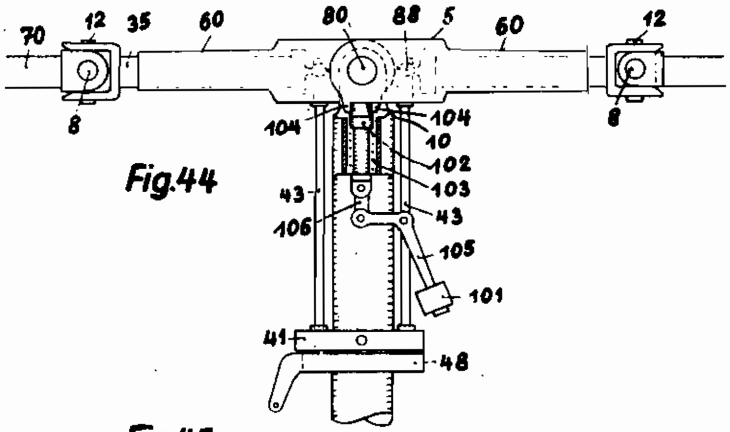


Fig.45

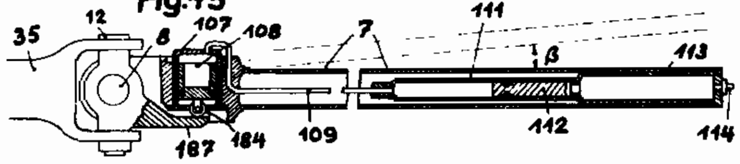
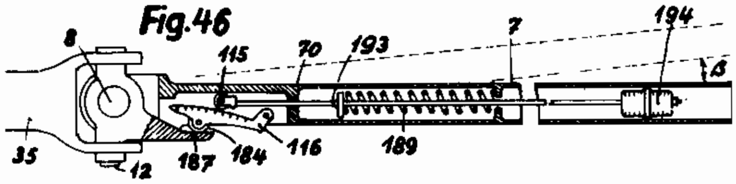


Fig.46



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Published May 25, 1943 **Serial No. 254,867**

ALIEN PROPERTY CUSTODIAN

HELICOPTER HAVING TWIN INTERMESHING ROTORS

Anton Flettner, Berlin-Johannisthal, Germany; vested in the Alien Property Custodian

Application filed February 6, 1939

The present invention relates to helicopters and in particular to helicopters having twin intermeshing rotors and wherein the extensions of the rotor shafts diverge upwardly and the distance between the hubs of the rotors is smaller than the radii of the rotors. For the sake of brevity an aircraft of this kind is hereinafter referred to as a double or twin helicopter; in such helicopters the rotors are generally driven, but in case of engine failure they may be arranged to autorotate.

In known helicopters having a rotor arrangement different from that mentioned above it is usual to join the rotor blades to the hub rotor shaft in such a manner that the blades are free to oscillate or flap with a motion perpendicular to their plane of rotation, and that the bending movements transmitted by the blades to the rotor shaft remain relatively small. On the other hand in rotor arrangements of the twin rotor kind particularly referred to in the first paragraph hereof, the risk has not so far been taken of allowing the rotor blades to flap freely in flight; on the contrary, in the arrangements of the aforesaid kind the possibility of movement on the part of the blades in flight in a direction perpendicular to the plane of rotation was limited by means of stops or even by fixing the blades rigidly in order to preclude the danger of the blades of one rotor coming into contact with the blades of the other rotor rotating in the opposite direction with respect to and intermeshing with the former. However, these mechanical measures for preventing mutual contact between the blades entail the drawback that, in flight, owing to the aerodynamic forces acting upon the blades, considerable and dangerous bending moments are transmitted by the blades to the rotor shafts and thus also to the fuselage, and this made the utilization of twin rotors of this kind practically impossible. The inner and central blade portions of two blades rotating in opposite directions intersect in the case of a twin rotor according to the invention, at a short distance only from each other, and, particularly in the case of the tapered blades preferably used which have a greater chord towards the root, they exert a great aerodynamic action upon each other. For the purpose of preventing blade oscillations it is therefore absolutely necessary, particularly in the twin rotor system, to ensure that the variation in thrust of a blade is as small as possible during its rotation. In the case of fixed blades or when flapping blades have insufficient freedom of movement, great variations in thrust occur during forward flight; in that case it is practically impossible to avoid two blades intersecting each other precisely at the point of maximum thrust. The tendency of the blades to forced vibrations would in that case be intolerably great.

A method of joining the blades to twin rotors which provides thorough equalization of thrust during forward flight has also already been described, the blades of which are however merely rotatable about longitudinal shafts rigidly connected to the hub: Contrary to the case of freely flapping blades, there occurs in this case at the root of the blade a thrust moment which is variable during the rotation. The hubs of the rotor and the aircraft are thus, despite the uniformity of the total thrust not free from bending moments inasmuch as during rotation, the centre of thrust moves longitudinally along the blade. The invention is based on the realization that in the case of twin rotor aircraft it is particularly important to avoid bending moments acting upon the hubs and the rotor shafts, namely for the purpose of keeping the dimensions of these component parts as small as possible and thus to facilitate the most satisfactory intermeshing of the rotors. For this reason it has been found to be far more satisfactory in the case of twin rotor aircraft to accept a certain amount of inequality of thrust and to tend instead to obtain a vanishing or almost vanishing thrust moment such as can be achieved by the arrangement of freely flapping blades.

According to the invention the drawbacks of the known twin rotor aircraft of the kind mentioned in the first paragraph hereof are overcome in that the amplitude of oscillation of a blade oscillating in a known manner with a component of motion perpendicular to the plane of rotation is limited in flight merely by means of aerodynamic forces. Contrary to expectations it was found on the basis of tests that this is sufficient to ensure the production of a practicable helicopter having also substantial advantages when compared with helicopters hitherto known. The new twin rotor machine possesses the advantage over the known helicopters having co-axially superimposed rotors that one rotor is not located in the downstream of the other rotor; on the contrary the so-called twin-rotors behave as a single rotor having two directions of rotation and which, contrary to other known helicopters having only one rotor, do not require additional means for counter-balancing the torque generated by the driven rotor.

Compared with the known and hitherto successful helicopters having two rotors disposed side by side and rotating in opposite directions and having a distance between their shafts amounting to more than twice the length of a blade, the new twin rotor helicopter possesses the advantage that it avoids the use of large outriggers which are very heavy and offer great air resistance and which are necessary in the aforesaid known helicopters owing to the great distance between the rotor shafts, and that moreover the aerodynamic efficiency of the two rotors is improved by the intermeshing and overlapping of the blades.

The various constructional forms of the invention comprise special inventive means partly new and partly known per se, which facilitate or promote the carrying out of the inventive idea, in particular means which minimize the flapping movement of the blades in flight without the use of stops or the like and, in case of emergency, for example in the case of wind gusts keep the flapping range of the blades of one rotor away from the flapping range of the other rotor. These various special basic means are described hereinafter with reference to the drawings, which however are intended merely to illustrate various forms of construction of the invention and of the said means by way of example.

Figure 1 illustrates the various positions of the blades in a known helicopter having only one rotor and direct control and freely flapping blades, the pitch and flapping angle of which are independent of each other, the illustration being a side view. The position numbered **1** is that taken up during slow forward flight: position **2** occurs when a wind gust strikes the blades from above: the blades then enclose an angle of more than 180°. The position numbered **3** is brought about during rapid forward flight, when the rear blade is deflected downwardly and the front blade is deflected upwardly. In the case of a helicopter of this kind there is a free flapping of the blades to below the horizontal position when no stops are provided for limiting the amplitude of the flapping motion or when such stops are not operative; thus it is advisable to avoid such stops in flight in order to prevent a transmission of dangerous bending moments and vibrations to the fuselage.

Figure 2 illustrates a side view of the positions of the blades under different conditions in a known helicopter having only one rotor similar to the rotor in Figure 1, wherein provision is however made for controlling not the entire head nor the entire hub of the rotor, but only the angle of incidence of the individual blades. The positions marked **1** and **3** correspond to the similarly numbered positions in Figure 1. The position **4** of the blades occurs in that controlling movement which is usually designed as "pulling up the nose of the helicopter". During this controlling movement the tips of the blades describe during their rotation and with a periodical alteration of their pitch, a circle in a plane (tip circle) which is displaced with respect to the fuselage in the same direction and to the same extent as when a corresponding controlling movement or displacement of the hub of the rotor in Figure 1 is carried out.

According to whether this backward inclination of the plane of the tip circle during rapid flight (position **3**) is greater or smaller than the backward inclination effected by means of an intentional control movement (position **4**), there will be need for greater or smaller free flapping angles in flight either in the case of the direct control according to Figure 1 or of the blade control according to Figure 2. Calculations and tests have shown that the blade control according to Figure 2 generally requires the smaller flapping angle.

Figure 3 illustrates a side view of an arrangement of the two rotors in a constructional form of double helicopter according to the invention, that is to say for rotors each having three blades, as seen in the direction of flight.

Figure 4 illustrates a plan view from above of the arrangement in Figure 3.

The direction of rotation of the rotors is preferably such that at the point of intersection of two blades the upper blade is moving in the direction of flight. The object of this arrangement is to prevent the air flow which is interrupted in the vicinity of the retreating blade from coming within reach of the succeeding blade advancing through the descending air flow.

Figure 5 illustrates a plan view of a corresponding arrangement of two rotors in a constructional form of double helicopter according to the invention, in this case for rotors each having only two blades.

Figure 6 illustrates in side elevation a constructional form of double helicopter according to the invention. The aerodynamic lifting force L exerted by the rotors on the fuselage of the aircraft possesses with respect to the centre of gravity S a lever arm *b*. Said lever arm *b* is so proportioned that the moment of the aerodynamic force L with respect to the common centre of gravity S of the aircraft is generally as great as the residual torque acting in the opposite direction of rotation with respect to the point S, said residual torque being due to the rotation of the rotor shafts in opposite directions and to their relative angular arrangement, the magnitude of said residual torque depending upon the torque of the two rotors.

As this torque reaction is not counter-balanced by the rotation in opposite directions of the rotors it may possess a variable order of magnitude, and provision is according to the invention conveniently made for a compensating controlling movement to be manually or automatically super-imposed upon the standard forward or blade control (Figure 1 or 2) or other usual aircraft controls, said compensating movement counter-balancing the torque reaction, which has not already been taken care of by suitably proportioning lever arm *b*.

Consequently, for the purpose of effecting this balancing out of the residual torque reaction there must be provided in such control members as may be fitted, guided control movements amplitudes which are larger than the corresponding guided control movements or amplitudes respective which would be necessary for a corresponding rotor-driven aircraft having two parallel rotor shafts.

Figure 7 illustrates a constructional form of a twin helicopter according to the invention corresponding to Figure 6 but seen from the front. This figure illustrates a few generally recommended features for twin helicopters according to the invention in particular the feature that the extensions of the rotor shafts which are shown in dotted lines (at A) intersect in the vicinity of the common centre of gravity S, and preferably above said centre of gravity. This arrangement is to be preferred in consideration of the thrust forces, which may be of unequal magnitude upon the two rotors for example owing to the lateral movement (sideslip of the aircraft) or in consequence of different pitch of the blades of one rotor with respect to the blades of the other rotor, the residual thrust reaction to said unequal thrust forces with respect to the centre of gravity S will however be small when the point of intersection A of the line of force lies in the vicinity of the point S. When this point of intersection A lies above the point S during the side slipping of the aircraft a stabilizing moment will be produced similar to the moment resulting from the known dihedral angle of the supporting surfaces of fixed wing aircraft.

Moreover, it is advisable, even if not absolutely necessary according to the invention, that in accordance with Figure 7 the line connecting the two hubs shall extend in manner known per se perpendicular to the direction of flight; for this arrangement offers the advantage that the aerodynamic conditions do not differ for the two rotors during forward flight and that is avoids the one rotor working in the downstream of the other rotor thus increasing the aerodynamic efficiency,—and this is important for avoiding mutual interference where the rotor blades intermesh.

Figure 8 illustrates a constructional form of the rotor of a double helicopter according to the invention as seen vertically from above. This form of construction is in turn recommended for intermeshing rotors, because the blades **7** are joined, not immediately adjacent the rotor shaft nor direct to the hub **5**, but by means of the flapping joints **8** to the arms **6** which are rigidly mounted on the hub and extend radially; due to this constructional measure it is a simple matter to keep the flapping range of the blades of one rotor removed from the flapping range of the blades of the other rotor, as will be seen from the following with reference to Figure 9.

According to the constructional form illustrated in Figure 8 and subsequently illustrated constructions, preference is given to relatively rigid rotor blades, these being at least as rigid as the hitherto usual blades, which when the trapezoidal shape is chosen may be made still larger; this in turn is done for the purpose of avoiding contact between the blades of one rotor and the blades of the other rotor also when extraordinary flying conditions occur suddenly, such as for example gusts of wind, which might cause the blades to bend.

Figure 9 illustrates diagrammatically the arrangement of two intermeshing rotors according to the invention. In this figure a indicates the distance of the flapping hinge of one blade **7** from the axis of rotation **10**, 2γ is the angle enclosed by the extensions of the two axes of rotation, β is the flapping angle of a blade **7**, said angle being positive when the blade is located above the imaginary plane passing through the hub perpendicularly to the axis **10**, the arms **6** also extending in the said plane.

According to Figure 10 an examination and graphic representation has been made of the free flapping angles of the blade which are possible in a rotor arrangement according to Figure 9 for various distances a between the flapping hinge and its axis of rotation. On the horizontal drum line of the diagram in Figure 10 there is marked off the distance x between the point of intersection of the plane projection of the centre lines or longitudinal axes of two blades **7** in Figure 9 which during flight happen to be exactly superimposed and the appertaining axis of rotation **10**. As a unit of length the distance between the hubs of the two rotors was taken to be $c—1$. On the vertical co-ordinate axis there are marked off the vertical distances y between the centre lines or longitudinal axes of the said blades **7** which just happen to be above each other, or between their radial hub arms **6** in the point of intersection of their plane projection. The three curves drawn apply to the following three values of the hinge distances a viz. 0.5, 0.7 and 0.9. These values at the same time indicate the ratio of a to c applicable to each individual curve.

The distances y have been calculated for a flapping angle of $\beta=—8°$, the blades stopping downward towards the plane of rotation. Moreover, as in the case of Figure 9, it has been accepted in Figure 10 that the angle of intersection enclosed by the two rotor shafts amounts to 24°, viz. $2\gamma—2\times 12°$.

In these circumstances it is found that the vertical distance y between two immediately superimposed blades and thus also the clearance available for additional flapping movements of said blades is greater the greater the distance a of the flapping hinge from the rotor shaft. Such clearance for additional flapping movements is generally required, because, as tests and calculations have shown, coning angles up to —10° downwardly occur at high speeds in the rear sector of the disc of rotation during the forward movement of the blade. Moreover, provision must be made for an additional downward flapping movement of the blade of about 6° when wind gusts from above influence the blades unless a limiting of this angle has been obtained by aerodynamic forces by means hereinafter indicated.

In connection with Figures 9 and 10 calculations and experiments have shown that it is advisable to choose the distance d between the flapping hinge **8** of the blade **7** of a rotor and the appertaining rotor shaft, so that it is about 0.8 to 1.2 times the distance c between the two hub centres, and further, if desired, to deviate from the arrangement of the hub arms **6** shown in Figure 9 by arranging said arms upon the surface of an upwardly open cone having the rotor shaft **10** as its own axis of rotation as illustrated in Figure 11. Owing to the above mentioned measures it is possible to keep the distance c between the centres of the hubs smaller than 10% of the diameter of a rotor, and the angle 2γ enclosed by the axes of rotation smaller than 30°, which is also recommended for constructional reasons for the purpose of carrying the invention into effect. By minimizing the angle γ, the loss in efficiency is also minimized, said loss arising from the fact that only the vertical components of the thrust of each individual rotor can be made to serve the purpose of sustaining the aircraft. Moreover, by keeping the distance c between the rotor hubs small, the air resistance is also kept low and the desirable displacement of the point of intersection of the axes of rotation above or in the vicinity of the centre of gravity of the aircraft is also thereby effected.

In Figure 11 the curves in Figure 10 have been used for the purpose of drawing the path of a blade of one rotor, above the hub **5** and the inclined hub arm **6** with the flapping hinge **8** and the shaft **10** of the other rotor. It will be seen from this figure that it is advisable to arrange the arms **6** of the hub upon the surface of an upwardly open cone above the rotor shaft also in order to adapt as far as possible the path of the said arms to the path of the blades passing above them.

Figure 12 illustrates a constructional form of rotor corresponding to Figure 11 having inclined hub arms **6**, drawn to a smaller scale and seen in side elevation. The arms **6** are mounted in a hub **5** which is rigidly connected to the rotor shaft **10**.

Figure 13 illustrates a constructional form similar to the form illustrated in Figure 12, wherein however the hub arms **6** are carried by a centre member **11** which is hinged at **9** to the rotor shaft **10**. Also in this case the hub arms carry the flapping hinge **8** of the blades, also drag hinges **12** which establish connection between the flapping hinge **8** and the hub arms **6**. A construction similar to the form illustrated in Figure 13 and having a corresponding centre member **98** is illustrated in plan view in Figure 20.

It is true that drag hinges **12** are known in helicopters having only one rotor or two nonmeshing rotors, but in the case of intermeshing rotors such drag hinges have hitherto been avoided, as it was assumed that the drag movement would involve the risk of the blades of one rotor coming into contact with the blades of the other rotor. Calculations which were confirmed by tests showed however that the horizontal amplitudes of oscillation of the blades in flight amount to only a few degrees, so that for the purpose of eliminating the transmission of bending moments or of reducing said bending moments it is advisable to utilize drag hinges which are known per se, also in the construction of twin helicopters.

According to further tests it was found that the rotor worked particularly smoothly when, in accordance with Figure 13 but contrary to the hitherto usual arrangement, the drag hinges are attached directly to the hub or to the arms **6** of the hub, that is to say on a part which does not oscillate during the rotation of the rotor, and between the flapping hinges **6** and the rotor shafts **10**. The reason for the smooth working thus obtained lies in that due to this arrangement of drag hinges the angle enclosed between the flapping hinge **8** and the blade axis does not vary.

Figure 13 further illustrates the arrangement of friction dampers **120** below the drag hinges **12**. This arrangement is recommended, as against the more usual arrangement above the drag hinges for double helicopters in general, as the only free space available in which the dampers can be placed is usually below the drag hinges without interfering with the clearance for the flapping movement of the blades or the clearance between the blades and the hub.

The construction according to Figure 13 affords a fundamental advantage compared with the construction illustrated in Figure 12 owing to the hinged attachment of the centre member **11** to the rotor shaft **18**, according to Flettner's German Patents No. 617,916 and 652,018 and 653,402. The use of this hinged arrangement as hereinafter described in further forms of construction illustrated in Figures 15, 19 and 20, is important precisely in a double helicopter, wherein for the above stated reasons, hub arms rigidly connected to the centre member are recommended inasmuch as these hub arms **6** form with respect to the rotor shaft **10**, lever arms for flapping moments, which would be transmitted to a considerable extent to the rotor shaft **10** and thus also to the fuselage, owing to the forces which would be exerted by the blades **7** upon the hinge joints **8** and **12**, if the centre member **11** had not been arranged to hinge with respect to said flapping moments.

In a rotor having three or more blades, universal joints preferably take the place of the joint **8** which is intended for rotors having only two blades. Instead of arranging such individual joints between each rotor shaft of the appertaining rotor, it will be sufficient for the purpose of avoiding transmission of flapping moments to the fuselage, to provide only one universal joint between the fuselage and a housing encasing in manner known per se the two individual rotor shafts **10** of the two rotors, and being adapted to be pivoted together with said rotor shafts.

Figure 14 illustrates a plan view of a form of construction of double helicopter according to the invention, wherein control screws **33** are provided. The pitch of the blades of said control screws may be adjustable in known manner (not illustrated) in order that the direction of thrust of the control screw may be altered at will according to the degree of control of the fuselage which is desired. The fact is that the use of such means of control, which are known per se, is recommended in particular for controlling the position of the fuselage in flight of a double helicopter having freely flapping blades and especially in connection with a forward control known per se according to Figure 1, or blade control according to Figure 2 (and Figure 20) in order that the additional flapping movements or inclinations of the blades of the rotors caused by such controlling may be kept small, in order to prevent all risk of contact between the blades of one rotor with the blades of the other rotor. To do this the controlling function of the rotors can be partly or wholly taken over by other usual means of control. In the latter case there is no need to use forward or blade control at all. Where these latter controls are preferred owing to other advantages, for example for hovering purposes, it is recommended that the direct control or the blade control be coupled with any other means of control; such coupling may be adapted to be engaged or disengaged at will. Control by means of the control screw possesses the advantage of remaining operative also when hovering.

However, instead or besides control screws, other usual control means such as rudders, elevators or ailerons may be used without or in addition to direct rotor control or blade pitch control. There may also be provided at the front or at the rear end of the fuselage one single control screw, for example one having a substantially vertical shaft; when the pitch of the blades of said control screw is simultaneously varied in the same direction, the effect is that of an elevator control; when the pitch of the blades is periodically varied during rotation in manner known per se, the effect is that of a lateral control. Finally elevator and lateral control can be effected by means of a pair of control screws having substantially vertical axes by simultaneously varying the pitch of all the blades of both or of only one of the control screws, when one of said control screws is arranged on one side and the other control screw on the other side of the fuselage at the front or rear end thereof.

When separate control screws are utilized in a double helicopter, these may serve the purpose of compensating for the residual torque reaction resulting from the relative angular arrangement of the rotor shaft **10**, by a simultaneous alteration of the pitch of their blades.

Figure 15 illustrates the mounting of a pair of blades in a construction of double helicopter according to the invention. In this case the rotor shaft **10** encloses an angle τ with the longitudinal axis of the blade **7**; the spar **68** connecting the two blades is mounted rotatably about its main axis at **800** in such manner that the pitch of a blade is reduced during the upward movement and increased during the downward movement of the blade. This effect is in general desired in the case of double helicopters having freely flapping blades in order to keep the range of the flapping movements which, in parenthesis are caused by the aerodynamic forces, as small as possible. The same remarks apply to the constructions according to Figures 18, 19 and 20 hereinafter described which are similar in this respect.

Figure 16 illustrates a constructional form of the invention in front elevation. In this case there is provided a housing **13** encasing the two rotor shafts **10**, the latter being mounted in the said housing. The housing is pivotable about a transverse axis or shaft **14** extending transversely of the direction of flight. The said transverse shaft is rotatably mounted in a bearing member **15** connected to the fuselage.

Figure 17 illustrates the construction according to Figure 16 in a side elevation. It will be seen that the transverse shaft **14** carries a control lever **160** which is freely rotatable upon said shaft, the lever being connected, by means of parallel link mechanism **17**, **18**, **19** to the head or hub **5** (compare Figures 1 and 2) so that when the freely rotatable housing is pivoted the angle of the swash plate **18** and thus at the same time the angle enclosed by the planes of the circles described by the tips of the blades **7** are not altered with respect to the fuselage. For this purpose the second rotor (compare Figure 16) possesses precisely the same control as illustrated in Figure 17, the control being omitted here merely for the sake of clearness. This mounting of the housing (**13**) encasing both rotor shafts has the advantage that an automatic compensating of the residual torque reaction resulting from the relative angular arrangement of the rotor shafts is effected about the transverse shaft **14**.

As mentioned in a general way in the case of Figure 13 there may also be provided in the case of the particular constructions illustrated in Figures 16 and 17 a universal joint-like mounting of the housing (**13**) about a further axis of rotation (extending perpendicular to the transverse shaft **14**, that is to say extending in the direction of flight) in order to keep lateral moments away from the fuselage.

Figure 18 illustrates a form of construction of the hingeing and control of the blades of a rotor according to the main claim of Breguet's German Patent No. 567,584, class 62*b* which may with advantage be used in a double helicopter according to the invention in order to keep the flapping movement as small as desired.

Figure 18 is a plan view of the said construction, partly in section. To the rotor shaft **10** there are hingedly attached at **90** the hub arms **800** in such a manner that together with the blades they are able to carry out flapping movements independently of each other about the axis **90**. Within the arms **600** there are located the control hinges **35**. At the outer end of said hinged shafts **35** there are mounted universal joints consisting each of a drag pin **12** and a flapping pin **8**, to which the blade spars **70** are attached. For the purpose of rotating the control shafts **35** control levers **134** act obliquely upon their outer ends, said control levers **134** being controlled by means of a push rod, which in the drawing is seen in a longitudinal direction, and a lever **142**. The lever **142** is firmly attached to a swashplate **141** which in a manner not illustrated in the drawing is universally mounted with respect to the rotor shaft **10**, and rotates when the rotor shaft rotates. Upon this swashplate there is rotatably mounted a guide ring **48** by means of a bearing **47**, the control handle **18** acting upon the said guide ring **48** for the purpose of tilting it in all directions.

With the arrangement shown in Figure 18, when a blade flaps upwardly about the hinge **90**, the pitch or angle of incidence of the blade is reduced, as the hinge **8**/**12** is moved upwardly with the upwardly moving blade, whilst the head **143** of the hinge is retained by the appertaining push rod **142** in its initially determined fixed position, so that the control lever **134**, is pivoted in the direction in which it reduces the pitch of the blade. Conversely a pivoting of the control lever **134** in the opposite direction causes the pitch of the blades to be increased during the downward flapping of the blades. Further explanations of details of construction regarding this control may be gathered from the specification of German Patent No. 567,584 and for the sake of simplicity they are omitted here.

In the arrangement illustrated in Figure 18 the aerodynamic forces acting upon the blades are utilized for the purpose of causing the desired independent automatic variation of the pitch of the blades during flight. This offers the advantage that also localized gusts, for example, acting upon one blade only, involve an automatic compensation by varying the pitch of this particular blade.

However, the arrangements for keeping the beating movements small are simpler from the point of view of construction, when in manner known per se the compensating control of one blade is made dependent upon a corresponding control of the pitch of the other blades or of the other blade by means of a pivotable centre member common to all the blades. Constructional forms of such arrangements the application of which to double helicopters according to the invention is to be preferred are illustrated in Figures 15, 19 and 20. Fundamentally the advantage which these arrangements have over Breguet's arrangement in Figure 18 is that all the blades cooperate in effecting a compensating of the pitch due to the aerodynamic forces acting upon said blades.

In other respects the constructions shown in Figures 15 and 19 are based upon the same fundamental idea as regards the arrangement and adjustment of the flapping hinges, as in Breguet's arrangement in Figure 18. This basic idea consists in providing a flapping hinge axis located at an angle with respect to the longitudinal axis of the blade due to which the pitch of the blade is reduced during the upward flapping of the blade and increased during the downward flapping of the blade. In the arrangement according to Figure 18 such a flapping hinge is not materially embodied yet virtually present, as the blades do in fact carry out a flapping movement about imaginary flapping shafts extending at an angle with respect to the longitudinal axes of the blades, due to the control described, by means of the firmly retained end 143 of the control levers 134. In Figures 15 and 19 on the other hand the flapping hinge for both blades and disposed at an angle is materially embodied in the form of the shaft 800.

Figure 19 illustrates a plan view of an inclined arrangement of the blades recommended also for twin helicopters and corresponding substantially to the arrangement in Figure 15, there being however provided for the blades in the former in addition to the inclined common flapping hinge 880, separate flapping hinges 8 upon stub axles 50 extending at an angle with respect to the shaft 800, in order to reduce the bending moments in the blade spars 70. The bearing of the shaft 800 forms part of the rotor shaft 10 and thus rotates when the latter rotates.

Figure 20 illustrates the already previously proposed method of reducing the pitch of the blade according to Flettner's German Patents 617,916, 652,018 and 653,402 when the blade flaps upwardly, and of increasing the said pitch when the blade is flapping downwardly. The use of such devices in double helicopters according to the invention is recommended as against the previously described method according to Figure 19, especially when the periodic individual control of the pitch of the blades, which is preferred for other reasons explained hereinafter, is to take place.

Figure 20 illustrates a plan view partly in section of such a control in a rotor having only two blades. However, it is an advantage in this kind of control that from constructional point of view it can easily be adapted to rotors having more than two blades in contradistinction to the controls according to Figures 18 and 19. In the last mentioned case of more than two blades, the hub carrying all the blades must be pivotable in all directions with respect to the rotor shaft, according to German Patents No. 652,018 and No. 653,402.

In the case of Figure 20 the rotor hub 110 which is common to the blades is pivotable about the shaft 900 merely in the manner of the beam of a balance, said shaft 900 being mounted in a part connected to the rotor shaft 10 and thus rotates when the latter rotates. The blades are mounted in the habby means of control shafts 35 which are hinged in the direction of the longitudinal axis of the blades and rotatable about the said shafts 35. The adjustment of the pitch of the blades about these shafts 35 is effected fundamentally in the same manner as in Figure 18 (according to German Patent No. 653,402) by means of the control arms 340, which are rigidly mounted on the shafts 35 and otherwise correspond to the control levers 134 in Figure 18. At a certain setting of this blade control the end points of the control arms 340 are fixed in respect to the rotor shaft, so that when the aerodynamic forces cause the hub 110 to be pivoted about the axis 800, the desired variation of the pitch is effected owing to the control shafts 35 being turned and the control arms 340 pivoted.

The control of the flying position of a helicopter or double helicopter, by means of periodic variation of the pitch of the individual blades during rotation, explained with reference to Figures 18 and 20 in the case of a rotor having two blades (or two intermeshing rotors each having two blades) (compare Figure 2) is recommended for a double helicopter according to the invention, also when using rotors having more than two blades because in the case of said control calculations and tests have shown that the necessary free flapping range of the blades is smaller than in the case of the usual direct control. The periodical adjustment of the pitch angles produced by the blade control is, in the case of a hub according to Figure 20 or a hub which is pivotable in all directions (Figures 16 and 17) so influenced, as may be seen in Figure 20, that a maximum value of the pitch angle is obtained in the position of a blade perpendicular to the drag hinge and on the side where the blade is moving downwardly. When the said rotor blade control is provided on both rotors of the twin-rotor helicopter, the fore and aft or the lateral control can be effected by common periodic variation of the pitch of the blades of both rotors in phase; in the case of fore and aft control the pitch of the blades of both rotors attains a maximum and a minimum value in the position in which the blades are located transversely to the direction of flight, whilst in the case of lateral control the pitch of the blades of both rotors attains a maximum and a minimum value when the blades extend in the direction of flight.

For the purpose of rudder control of the double helicopter according to the invention the blade control may also be utilized by increasing the pitch of all blades of the one rotor and/or reducing the pitch of all blades of the other rotor.

It has not hitherto been attempted to use this kind of rudder control, which is known in the case of helicopters having co-axially disposed rotors, in double helicopters having freely flapping blades, as said control increases the coning angle of the one rotor whilst reducing the coning angle of the other rotor, thus increasing the danger of the blades hitting each other. Careful calculations show however that it is possible also in the case of the said control to avoid the danger of the blades coming into contact.

For twin helicopters according to the invention it should be noted in particular that it is known that a lateral inclination of the plane of the tip circle of the blades occurs when the flying speed increases, (increasing tip speed ratio) in the direction of the side upon which the blades move in the forward direction. The inclination of the planes of the tip circle of the blades of rotors rotating in opposite direction is thus either directed towards each other or away from each other according to their direction of rotation. Both alternatives are undesirable, as in the one case there occurs an unnecessarily large angle between the rotor shafts with a corresponding loss of power and the other case increases or involves the risk of the blades of one rotor coming into contact with the blades of the other rotor.

This drawback can be overcome according to the invention by initiating, by means of the fore and aft control a lateral tilting of both planes of tip circles according to the direction of rotation of the rotors either toward or away from each other. This avoids dangerous tilt positions as the position of the fore and aft control determines the flying speed or the tip speed ratio, which latter causes the undesired lateral inclination.

The particular conditions of stability in a double helicopter according to the invention during the forward flight may in certain circumstances make it appear advantageous to couple the fore and aft control (inclination of the blade tip circle) with the operation mechanism of elevator control surfaces of the usual design, in such a manner that both controls are actuated at the same time, this being ensured by means of a positive coupling.

As the lateral inclination of the tip circles of the blades which has been provided as being suitable involves the risk of the blades of one rotor coming into contact with the blades of the other rotor, it may be found advisable to make the said lateral control effect relatively weak and to so proportion it to ensure hovering or rising without forward movement. For forward flight this control should then be supplemented by the action of lateral control surfaces of the usual design which are operated simultaneously and do not become operative until forward flight takes place. For the purpose of attaching the lateral control surfaces an additional fixed wing should be provided on twin helicopters.

For the purpose of avoiding undesirably large flapping angles when directional control is effected by mutual variation of the blade pitch of both rotors it may be found advantageous to make the available directional control weak, also proportioning it in such a manner that it will be just sufficient to ensure hovering or rising without forward movement. This control should then be supplemented by the action of a directional rudder of the usual design being operated simultaneously but operative only during forward flight.

When it is desired to eliminate ab initio any risk of the blades coming into contact with each other owing to the inclination of the tip circles in the direction toward each other in the case of forward control and when using rotor shafts pivotable in all directions, the common housing mentioned in connection with Figures 13 and 17 and encasing both rotor shafts may be utilized for this purpose, as it is pivotable in all directions with respect to the main driving shaft connecting it to the fuselage. This at the same time offers the advantage that no bending moment can be transmitted from the twin rotor system to the fuselage, when the blade control which for example may be provided is in manner known per se and as hereinbefore described so arranged that such bending moments cannot be transmitted to the fuselage by the control rods.

The free movability of the said housing can however in certain circumstances give rise to oscillation during flight. In this case it may be found advantageous to effect the rotation of the housing in a positive manner by means of a system of rods controlled manually or automatically when variations of the residual torque occur due to the relative angular arrangement of the rotor shafts.

Figure 21 illustrates a front view partly in section of a form of construction of the drive of the twin helicopter according to the invention. There would be a temptation for the purpose of designing a drive to connect the two rotor shafts **10** of the double helicopter to each other by means of a single pair of bevel gearwheels and to the main driving shaft **28**. This method of transmitting the drive would however be unsatisfactory in practice, as helical bevel gears having such a small angle of intersection resulting from the preferred rotative positions of the rotor shafts, are difficult to produce. It is therefore more advantageous in the case of a double helicopter according to the invention as illustrated in Figure 21 to drive the two rotor shafts **10** by means of two pairs of bevel gearwheels **23**, **24** from a single shaft **25** extending parallel to the line connecting the two hubs. This shaft **25** is mounted in a housing **213** transversely of the direction of flight, said housing being firmly or, according to Figures 16 and 17, pivotally attached to the fuselage. The common or main driving shaft **26** coming from the engine drives the transverse shaft **25** by means of bevel gearwheels **27**, **28**.

Another method of driving the two rotor shafts of a double helicopter according to the invention is diagrammatically illustrated in Figure 22 (in front and side view). In this simplified form of construction the drive of the two rotor shafts is effected by means of intermediate shafts interposed in the manner of universal joints and having each a wormwheel **230** actuated by a common worm **270**, the shaft of which extends perpendicular to the plane in which both rotor shafts lie. The shafts **29** and **30** of the wormwheels **230** extend parallel to the rotor shafts **10**.

In many cases it will be necessary to arrange the engine with a horizontal shaft in the fuselage. In a double helicopter according to the invention the gearing connecting the two rotor shafts to each other may be disposed level with the engine shaft. Figure 23 illustrates diagrammatically a front view of a construction intended to meet this case. The axes of rotation of the rotors are connected by means of the joint shafts **31** and the shafts **100**, which are carried by a gearbox (not illustrated) and extend parallel to the rotor shafts, to the bevel gearwheels **23**. The gearwheels **23** mesh (as illustrated in Figure 23) with the gear-wheels **24**, which by means of a further bevel gearing are driven by means of the common shaft **25** of the said bevel gearing. This arrangement is satisfactory as it results in the common, centre of gravity of the aircraft being relatively low so that both stability on the ground as well as stability of the double helicopter in flight are improved. The shafts **100** which are connected to the rotor shafts of the rotors by means of hinged shafts **31** and which are carried in the gearbox must be parallel to the rotor shafts in order to ensure uniformity of drive, which would not be the case when the hinged shafts were each connected to one rotor shaft and the said rotor shaft were not parallel.

Due to the short distance between the two rotor hubs it is possible in a double helicopter according to the invention to enclose both rotor shafts and their bearings in one common streamlined casing lying preferably flush with the contour of the fuselage, as illustrated in Figures 6 and 7. The double helicopter is in this manner given an appearance and the aerodynamic qualities of a helicopter having only one rotor which to a certain extent corresponds to the twin rotors rotating in opposite directions according to the invention.

The constructional forms illustrated in Figures 24–30 and hereinafter described relate to improvements in the hinging of the blades of a helicopter according to the invention. The idea underlying these improvements which offer particular advantages in the case of double-rotor helicopters, are however generally applicable to helicopters having blades which flap freely in flight about flapping hinges and the flapping axes of which enclose acute angles with the longitudinal axes of the blades. The inclined flapping axes of the blades should preferably point outwardly in the direction of rotation. As is known and as illustrated in Figures 15, 18 and 19, the result of this is the desired interconnection between the flapping angle and the pitch angle of a blade such that the pitch angle diminishes in upward flapping and increases in downward flapping; the degree of this interconnection depends upon the magnitude of the acute angle enclosed by the flapping axis of the blade and the longitudinal axis thereof.

In all rotating wing aircraft (helicopters and auto-rotating gyroplanes) having freely flapping blades, endeavours have always been made to arrange the flapping hinges as closely as possible to the centre of the rotor in order to avoid bending moments on the rotor shaft. Now, when it is desired to fix drag hinges for the blades preferably perpendicular to the flapping hinges, as is known in the case of flapping hinges which are at right angles to the longitudinal axis of the blade, the said drag hinges must be arranged at a certain minimum distance from the centre of the rotor in order to avoid undesirably large angles of lag of the blade. It is therefore an obvious and also usual manner of construction to fulfil the two conditions, viz. minimum distance between flapping hinge and centre of rotor, and at the same time a certain minimum distance between the drag hinge and the centre of the rotor, by arranging the flapping hinge nearest the centre of the rotor and the drag hinge further out in the direction of the tip of the blade. This sequence of the hinges is satisfactory for helicopters in the case of which there are only very slight deflections during flight of the blade at the drag hinge. In the case of helicopters, large angles of lag of the blades occur proportionately with the magnitude of the driving torque. In the case of the aforesaid usual arrangement of the hinges, the angle enclosed by the flapping and the longitudinal axis of the blade increases as the angle of lag increases, and thus the degree of coupling between the flapping angle and the pitch angle of the blades is also altered. This applies also in the case of arrangements in which the flapping hinge is approximately at right angles to the longitudinal axis of the blade and tests have shown that even in this case the smoothness of the rotor is appreciably interfered with owing to the fact that the interconnection between flapping angle and pitch angle varies with the variation of the angle of lag. The relative alteration of the degree of interconnection is therefore the greater, the more acute the angle between the flapping axis and the longitudinal axis of the blade is chosen. But it is precisely in the case of inclined flapping hinges that it is necessary to make the interconnection between the flapping angle and pitch angle independent to the magnitude of the angle of lag of the blades.

This is achieved according to the present invention by arranging a drag hinge between the centre of the rotor and each of the flapping hinges. In this manner the angle ϑ (compare Figure 27) between the flapping axis and the longitudinal axis of the blade is made independent of the drag angle and thus also independent of the driving torque. Where as is usual, special hinges (control hinges) are provided in addition to the flapping hinges and drag hinges between the centre of the rotor and the flapping axes, the blades being adjustable about said control hinges by means of a control, the drag hinges are according to the present invention preferably interposed between the control hinges and the flapping hinges. The theoretical axes of the three hinges of each blade arranged in the sequence according to the present invention may in the case of a suitable constructional form intersect in one point in order in this manner to avoid interference from moments about the control axes.

The axes of the control hinges which serve the purpose of altering the thrust or the position of the circle described by the tips of the blades usually extend in the direction of the longitudinal axis of the blade or approximately parallel thereto. However, according to the present invention the axes of the control hinges should preferably extend almost perpendicular to the longitudinal axis of the blades, because in this case a satisfactory constructional form results even in the case of relatively acute angle between flapping axis and longitudinal axis of the blade.

According to the present invention the drag hinges may be disposed in an inclined position so that downwardly they point in the outward direction. Tests have shown that in the case of a combination of a drag hinge of this kind and an inclined flapping hinge having an axis directed outwardly in the direction of rotation, the coupling of the angles of flapping, angle of lag and pitch is such that friction dampers perpendicular to the blade axis required in the case of drag hinges can be omitted and forces thus avoided in the control.

In the constructional forms illustrated by way of example of this improvement, Figure 24 shows a constructional form in side elevation in the case of a two-bladed rotor, Figure 25 a diagrammatic view of a portion of the control, Figure 26 a vertical section through the control hinge **35** of the constructional form illustrated in Figure 1; Figure 27 is a plan view of the constructional form illustrated in Figures 24 and 26 partly in section through the control axis **35** for various drag angles; Figure 28 a further constructional form in plan view in the case of the three-bladed rotor; Figure 29 a modified constructional form similar to the form illustrated in Figure 28, in side elevation; Figure 30 is a plan view of the constructional form illustrated in Figure 29.

Figure 24 illustrates the arrangements of drive, hinges and controls for the blades of a helicopter rotor having only two blades. In this figure the blades are shown as being broken off the blade roots or spars **70**, whilst in Figures 25 and 26 a portion of the sustentory blade surface **7**, attached to the blade spar **70** may be recognized. The blade roots **70** form axes **8** for a flapping hinge, which is attached at **80** to the forked ends of the arms **500**.

The arms **500** possess a common control hinge **35** by means of which said arms are hinged in the centre of the upper end of the rotor shaft **10**. Said hinge **35** of the control hinge extends almost at right angles to the longitudinal axes of the blades. Each of the two hinges **8**, **80** is mounted between the prongs of the fork of the arms **500** by means of the drag hinge **12**, the rotation of which is damped by dampers **120**. The drag hinges **12** extend at right angles to the flapping axes **8**.

Push rods **43** (Figures 24 and 25), for controlling the arms about the hinge **35** act upon the forked ends of the arms **500** by means of universal joints **34** in a direction almost parallel to the extension of the drag axes **12**. At their lower ends the push rods **43** are connected by universal joints **340** to the arms **42**. The arms **42** at the same time each form the axis **45** of a universal joint the other components of which are the intermediate ring **38** and the other axis **44**, the latter mounted in the push rod **54** which is arranged longitudinally slidable in the elongated slot of the axis of rotation **10**. The universal joint axis **44** is also mounted vertically slidable in the elongated slot **71** of the rotor shaft **10**. An up and down movement of the lever **54** effects a uniform alteration of the thrust of all the blades. When the rotor shaft **10** rotates, the universal joint **44/38/45** also rotates. A guide ring **41** is pivotably mounted upon the axes **45** and carries on its lower portion a ball bearing **47**. The outer race of the ball bearing **47** lies within a control ring **48** carrying a lever **49** which is retained against rotation about the axis **10** on the fuselage by means of levers not illustrated in the drawing. By means of a control lever **16** the lever **49** may be pivoted in all directions about the universal joint by the pilot. By this means the plane of the circle described by the tips of the blades **70** of the rotor may be inclined as desired.

Figure 27 illustrates in heavy lines the pivoted position of the right blade **7**, **70** with respect to the position shown in Figure 26, whilst the non-pivoted position is shown by dotted lines. It will be seen from this figure that the acute angle which the longitudinal axis of the blade encloses with the axis **8** of the flapping hinge is independent of the pivoting movement in both cases.

In the case of the constructional form illustrated in Figure 28 three blades are provided, each being attached to a hub arm **6** by means of a flapping hinge, **8**, **80**, a drag hinge **12** connected and perpendicular thereto, and a control hinge **35** connected and perpendicular to the drag hinge, the hub arm being rigidly connected to the rotor shaft **10**. For the sake of clearness only one blade is shown whilst the other two hub arms **6** are shown as broken off. The hinges are in accordance with Figures 24, 26 and 27 arranged between the fork end of the hub arms **6**, in which however not the drag hinge axes **12**, but the control hinge axes **35** are directly rotatably mounted. At the end of each control hinge axis **35** there is firmly attached a control arm **88** attached to the control ring by means of a universal joint **34**. The control can be transmitted to the control ring **41** in the same manner as in Figures 24–27, which should be connected to the rotor shaft **10** so as to be both pivotable with respect thereto, slidable in the longitudinal axis thereof and rotatable when the rotor shaft rotates. Also in the case of this constructional form the hinge axes of the control hinges **35** extend almost perpendicular to the spar axis of the appertaining blade.

Figures 29 and 30 illustrate a constructional form corresponding to Figure 28 wherein however the drag axis of the drag hinge **12** enclose an acute angle ψ with the spar axis of the appertaining blade **7**. The arms **88** for controlling the control hinge (**35**) in this constructional form are according to Figure 1 connected to the control ring **41** by means of universal joints **34** and push rods **43**. The control ring is connected to a universal joint and to a system of control rods **16** in exactly the same manner as described with reference to Figures 24 and 25. The same kind of constructional form of control can also be utilized in the constructional form illustrated in Figure 28, in which for the sake of clearness the said control is not illustrated in detail.

In the case of the arrangement according to Figure 28 it would be quite possible from the point of view of construction to interpose the drag hinge between the control hinge and the centre of the rotor. Said drag hinge would then of course be pivoted simultaneously with the drag movements of the arms **88**, so that the universal joints **34** and **340** in Figure 29 would no longer be located perpendicularly above each other and kinomatic errors would occur in the controlling especially in the case of inclined drag hinges (Figure 29). Whilst the improvements developed with the aid of Figures 24–30 refer in the first place to the sequence of blade hinges as arranged in the case of helicopters in so far as said improvements may be of advantage in all helicopters, the constructional forms illustrated in Figures 31–38 are restricted to the arrangements and improvements being applied to double helicopters or twin-rotor helicopters according to the present invention. In this arrangement there is a substantial improvement, independently of the sequence of the blade hinges, namely that the flapping axes of the blades are outwardly directed in the direction of flight and enclose an acute angle with the blade spar axis of the appertaining blade,—even if in the case of a helicopter having only one rotor the said arrangement constitutes no advantage. In the case of the double helicopter according to the present invention this precautionary measure does however, as will be seen from the statements in reference to Figures 15, 18 and 19, facilitate the solving of the problem of avoiding, during starting and landing and also under extraordinary flying conditions, mutual contact between the freely flapping, intermeshing blades of the two rotors.

The constructional forms illustrated in Figures 31–38 relate to control arrangements which are particularly suitable in the aforesaid case, said constructional forms being important in the case of double helicopters also independently of the control arrangement.

The manner hereinbefore described of inclined hinging of the blades is admittedly known in the case of co-axially superposed rotors, but particular importance attaches to said inclined hinging in the case of double helicopters according to the present invention, where it is important on the one hand to limit the range of the flapping movements and on the other hand to maintain the freedom of the flapping movements and to ensure during rotation a uniform thrust also at high ratios of forward speed to tip speed. A thrust which is uniform over the whole rotation is obtained according to the general explanation given at the beginning hereof, by the aid of freely flapping blades. Now, when however the blades are hinged by means of a flapping hinge according to the improvement illustrated in Figures 24–38 uniformity of the thrust also at tip speed ratio is obtained as a result of the flapping movement itself owing to the relative alteration of the angle of incidence, without causing the flapping movement to become too great; in fact where each flapping hinge axis about which the blades oscillate, extends at an angle to the blade spar axis smaller than 90°, there occurs simultaneously with the flapping movement a kinematically produced alteration of the angle of incidence tending to counter-balance the thrust, when the flapping axis is located in front of the blade spar axis in the direction of rotation.

Figures 31, 32 and 33, 34, 35 and 36 illustrate diagrammatically partly in plan view, partly in side elevation one constructional form each of the improvement whilst Figures 37 and 38 illustrate in perspective and in front elevation the application of the improvement to a helicopter or double helicopter and the controls and drive of the helicopter.

Figure 31 is a plan view of one constructional form; the blade **7** is connected to the arm **6** and the hub **5** by means of an inclined flapping hinge **8**, a control hinge **35** being interposed. The axis of the flapping hinge **8** encloses an acute angle ϑ with the blade spar axis. Owing to the inclined position of the hinge each upward and downward movement of the blade is connected with an alteration of the angle of incidence of the blade. In flight the blade assumes in known manner a position of equilibrium under the action of centrifugal force, inertia and aerodynamic forces. Now, when as a consequence of a gust of wind or the like, there occurs for example an increased upward thrust, the blade flaps upward and at the same time reduces the angle of incidence. This in turn reduces the upward thrust and the flapping movement of the blade is almost brought to a standstill. The control of the rotary blade may be effected by rotating the control hinge axis **35** by the aid of a lever **34**. In this case the hinge may be controlled periodically during rotation (altitude and lateral control) or simultaneously for all blades (directional control, change over from helicopter to autorotating gyroplane). The action of the control hinge is such that the blade flaps about a mean pitch position, which is controlled by the position of the control lever **34**. When for example the ball head of the lever **34** is set low down the result is a large angle of incidence for the mean position of the blade and corresponding increase in the thrust of the blade.

Figures **32** and **33** illustrate a similar constructional form in plan view, wherein however a further drag hinge **12** is provided which is advantageous for the purpose of reducing the moments and forces in the plane of rotation. In the said drag hinge **12** a friction damping device or the like may be incorporated. In this constructional form it is important that the drag hinge **12** be arranged closer to the hub than the flapping hinge **8**. The sequence of the hinges is such that the control hinge **35** is attached nearest the hub, then follows first the drag hinge **12**, and then the flapping hinge **8**. The advantage of this arrangement lies in that the angle between the blade spar axis and the flapping hinge is not altered when the blade oscillates about the drag hinge, so that also in the event of the blade lagging backward the relation between flapping angle and pitch angle remains unaltered once it is set to the position which is found to be satisfactory. By arranging the control hinge nearest the hub kinematic errors of control are avoided.

Figure 32 illustrates for example the conditions in the case of a gyroplane and **Figure** 33 the conditions in the case of a helicopter. In the helicopter condition the blade lags behind the hub, but the angle ϑ is maintained despite this lagging, and thus also the degree of coupling between pitch angle and flapping angle remains unaltered.

Where circumstances permit (heavy blades, high rotational speed), the angle ϑ may be less acute than illustrated in Figures 30–33. In these cases it is advisable to effect control by rotating the hinges about an axis which as far as possible coincides with the blade spar axis. Such a constructional form is illustrated in plan view in Figure 34. The blade **7** is connected to the control hinge **35** and the hub **5** by means of the flapping hinge **8** and the drag hinge **12**. The control hinge is located in the extension of the blade spar axis and is cyclically or simultaneously adjusted by means of the lever **34**.

In order to avoid vibrations due to the flapping movements of the blades being transmitted to the hub or to the control, a further flapping hinge **28**, may be provided further out along the blade. This hinge also has the considerable advantage that the maximum movement permitted by the main hinge **8** may be still further reduced so as to allow movements to be carried out only about the auxiliary hinge **28** for example in the case of heavy loads (strong gusts of wind). By choosing an acute angle between the auxiliary hinge **28** the blade spar axis in the same manner as between the main hinge **8**, a very great reduction in upward thrust can be coupled to the flapping angle, so that no great stresses occur at the inner portion of the blade even when the rotation about the main hinge **8** outside the normal range of rotation is limited by means of a stop.

The constructional form illustrated in Figure 35 (side elevation), and in Figure 36 (plan view) has the advantage that bulky component parts such as friction dampers may be omitted; by inclining the drag hinge **12** to an angle of ψ and having suitably chosen the rotary blade conditions, it is possible to obtain a damping of the drag movement, without the necessity for providing additional friction dampers. As a result, the constructional height of the hinge may be reduced. Further advantages are gained in that by suitably choosing the inclination of the hinge and the distance from the axis, an automatic alteration in the angle of incidence is effected, namely in that when driven, the blade lags and increases the angle of incidence. In the same manner the angle of incidence would automatically be adjusted from that of a helicopter to that of gyroplane as soon as the motor drive breaks down or is throttled back. The essential and also hitherto unknown point is that the inclined drag hinge **18** is nearer the hub than the flapping hinge **8**, as in that case the angle ϑ is independent of the driving torque.

Figure 37 illustrates diagrammatically a helicopter arrangement with the appertaining control arrangement for the adjustment of the pitch angle of the blades. The figure illustrates only one rotor hub (**5**) having two blades only partly drawn: however the control device is arranged so as to act upon the blades of two rotors which may be disposed with respect to each other according to the invention.

On the control hinge axes **35** which are rotatably mounted in the hub **5**, there are located rigid and bent control arms **880**. Two push rods **43** act upon the said control arms by means of universal joints **34** the lower ends of the said push rods being connected to a rod **410** by means of universal joints **52**. The rods **410** constitute a portion of the outer Cardan ring **41**, which together with the two pins **440** and **420** and the inner Cardan ring constitutes a universal joint pivotable in all directions. The axis **420** passes through longitudinal slots **71** in the rotor shaft **10** and is entrained by the rotor shaft when the latter rotates. The drive of the rotor shaft **10** is not illustrated. The axis **420** is mounted in the push rod **54** so as to be slidable together with the latter in the longitudinal direction of the rotor shaft **10**.

The Cardan ring **41** possesses a collar **460** upon which a further control ring **48** acts by means of a ball bearing **47**. The control ring **48** is connected to the control rod **49** by means of a joint **53**. The parts just described of the control arrangement, with the exception of the rod **49**, are symmetrically duplicated in the case where a second rotor is to be simultaneously controlled, whilst the rod **49** and the controlling parts about to be described are common to both rotors.

In the centre of the rod **49** there is mounted by means of a universal joint **55** a control rod **490**, the upper end of which is joined by means of a universal joint **56** to a fixed part **57** of the fuselage. The lower end of the control rod **490** is connected by means of a universal joint **59** to the usual control lever or stick **16**. Said lever **16** is pivotably mounted at **59** in a fork-ended part **72**, which at one end is rotatably mounted at **63** in a direction perpendicular to the direction of the drag hinge **59** and of the lever **16**. The bearing **63** is located in a part **64** firmly attached to a shaft **61** which is rotatably mounted in two fixed parts **62** of the fuselage.

The fixed parts **62** of the fuselage further constitute a bearing for a shaft **69** to the ends of which fork pieces **67** are keyed. The split ends of the fork pieces **67** encase pins **66**, projecting from the outer portion of a thrust bearing **65**, by means of the inner portion of which the rod **54** is rotatably mounted.

A control lever **66** sets upon the shaft **69** at one of the fork pieces **67**, the said lever enabling the fork ends to be pivoted about the axis **69**. During such pivoting movement of the lever **68** the rod **54** is displaced in the longitudinal direction with respect to the rotor shaft **10**, the rod **420** being at the same time displaced in the direction of the slots **71**; at the same time the push rods **43** are also thereby displaced and the control lever **860** together with the control axes **35** are rotated.

The control lever or stick **16** makes it possible, as will be seen, by means of the control arrangement described, to effect a pivoting of the blades **7** in opposite direction for any desired point of the path of rotation in such a manner that this adjustment is maintained for each point of the path of rotation and continues to recur cyclically during the rotation. In this manner the position of the described tip-circle-disc is controlled. The same applies at the same time to the second rotor which may be connected to the system of control levers.

The lever **66** further makes it possible to pivot all the blades of one or both rotors in the same direction in such a manner that this adjustment is maintained in equal measure through the entire rotation of the blades, independently of the adjustment which the lever **16** may superpose thereon. In this manner the lever **68** serves to alter the thrust of one or both rotors.

Figure 38 illustrates partly in section a front elevation of a double helicopter wherein the control arrangement according to Figure 7 has been provided for both rotors; the system of control rods attached to the joint **55** of the control rod **49** which is common to both rotors has been omitted for the sake of clearness, only the links **580**, **160** for guiding the control being illustrated in this figure.

The two rotor shafts **10** are mounted in a common housing **130**, containing the driving gear for the rotor shafts. This driving gear consists, as illustrated in Figure 21, of a pair of bevel gearwheels **23** keyed to the rotor shafts and engaging a pair of bevel gearwheels **24** both of which are firmly keyed to a shaft **25**. On the said shaft there is keyed a bevel gearwheel **28** engaging a bevel gearwheel **27**, which in turn is firmly keyed to a shaft **72** mounted in the housing **130**, and connected by means of a universal joint **73** and a further shaft **74** to the driving motor which is not illustrated in the drawing. The said driving motor is located in the fuselage **75** which is adapted to taxi on the ground by means of an undercarriage **76** with carrying wheels **77**.

The constructional form illustrated in Figures 39–46 represents a further improvement upon a double helicopter according to the present invention. The improvement provides other means than the means illustrated in Figures 24–38 for meeting cases in which owing to the use of freely flapping blades or blades oscillating about an inclined or virtually inclined hinge, there occur during the starting or braking of the rotors, instances in which the relative wind or a gust of wind would force individual blades upwardly or downwardly. This might occur especially where the rotors are rotating at a low speed of revolution, namely while the centrifugal force is still below a certain minimum value. In these cases there may thus be a risk that the blades of one rotor would come into contact with the blades of the other rotor.

It is the object of the improvement especially in such cases to arrest or to limit the flapping or oscillating movements and if desired also the drag or control movements of the blades about the hinges concerned. Such a limitation or arresting of the blade movements while on the ground or when starting or braking the rotors, that is to say at low speeds of rotation, has been proved to be advisable also for the purpose of enabling other parts of the aircraft (such as the undercarriage, control screws or the like) to be disposed nearer to the rotor blade planes of rotation, or for reducing the height of the aircraft and increasing ground clearance.

According to the improvements these aims are reached owing to the fact that the movements of the flapping and/or drag and/or control hinges are separately or simultaneously limited manually or by centrifugal force by means of stops controlled by mechanical, electrical, hydraulic or pneumatic controlling means, which when a certain rotational speed is exceeded or in the case of manual operation allow complete freedom in the range of movement.

Figure 39 illustrates in side elevation a stop controlled by centrifugal forces. The blade spar **78** is hinged by means of the flapping hinge **6** and the drag hinge **12** to the fork end **79** of the hub arm **6**. Before the commencement of a flight there is located between the blade spar **70** and the stop of a hinge part **78** connected to the hinge axis **12**, a pair of rollers **84** attached to a link **83** which is hinged at **86** to the blade spar **70**. The link **83** guides a roller **85** which in the position of rest is located between fork-shaped stops **87** of the fork end **79** and **91** of the hinge part **78**, the latter possessing a damper **120**. (Only the rear fork parts of the stops **87** and **91** are visible on the drawing.)

Figure 40 illustrates the T-shaped arrangement of the rollers **84** and **85** which for the sake of clearness are shown in perspective. The rollers **84** (Figure 39) prevent the blade from failing to reach a certain flapping angle; whilst the roller **85** limits the drag movement in the desired manner. As the rotational speed increases during starting, the centrifugal force of the parts **83, 84, 85** increases until it is sufficient to release the hinges. The parts then assume the position shown in dotted lines, in which the rollers **84** impinge upon a stop **92** of the blade spar **70**. This position is maintained during flight until the rotor is braked after landing and falls below a certain speed of rotation in which whereupon the stop rollers again enter between the hinged parts.

In order to ensure simultaneous release of all blades during starting it will be found advisable after reaching a certain speed of rotation to throttle the engine for a short moment or to disengage it from the rotors, as this will relieve the rollers **84, 85** of load so that their friction upon the stops ceases and they are free to move outwardly.

Figure 41 (side elevation) illustrates another stop controlled by centrifugal force. In this case two rollers **840** and **850** constituting a T-shaped arrangement are in a manner similar to the stop illustrated in Figure 39 pushed in between the flapping hinge **8** and the drag hinge **12** in the position of rest. In order to attain greater actuating force there is arranged at a greater distance from the axis of rotation **10** of the rotor, in certain circumstances within the section of the blade **7**, a weight **94** upon a push rod **93**, also carrying rollers **840, 850.** A spring **88** which forces the roller **840** and the push rod **93** inwardly and bears against a shoulder **98** of the blade spar **70**, is so proportioned that the rollers **840, 850** do not release the stops **87, 91** and thus allow complete freedom of movement until a pre-determined speed of rotation has been reached.

Figure 42 (side elevation) illustrates a stop for the flapping hinge **8** in the form of an eccentric. The blade spar **70** rests upon a lip **780** of the hinge part **78**, an eccentric **95, 96** being interposed. The eccentric axis **95** is rotatably mounted in the fork end of the blade spar. The eccentric proper **96** is rotated through 90° or less by means of a push rod and link **930**, as soon as the centrifugal force of a weight **940** overcomes the force of a spring **890** interposed between a collar on the rod **930** and a part **980** attached in the blade spar **70**, which spring pushes the rod **930** inwardly. In this manner the range of movement about the periphery of the eccentric is increased, that is to say the blade is practically allowed complete flapping freedom.

The eccentric may also be so designed, if desired, as to be controlled by the pilot.

The stops controlled by centrifugal force or by any desired means (**84, 85, 840, 850, 95**) may in appropriate manner be applied also to inclined flapping and inclined drag hinges, for example hinges as utilized in the constructional form illustrated in Figures 31–38.

Figure 43 (side elevation) illustrates such an arrangement. Both the flapping hinge **8** as well as the drag hinge **12** are in this case arranged in an inclined position with respect to the blade spar axis **70**. The rollers **840, 850**, arranged so as to constitute a T push themselves owing to the force of the spring **890** in between the hinge stops in a manner similar to the rollers in the previous arrangements, of which stops only the stop **87** being illustrated in the drawing for the sake of clearness. The spring **890** which on the one hand bears against the transverse member **99** of the push rod **930**, and on the other hand against the part **980**, is already counter-balanced by the centrifugal force of the weight **940** at low speeds of rotation.

The rollers **840** and **850** are preferably domed or spherical; in the same manner the faces of the stops may be conical to suit the movements about the hinges.

Figure 44 (side elevation) illustrates the design of a stop **101** controlled by centrifugal force for limiting the flapping movements of two oppositely arranged blades. The constructional form of the hinging of the blades corresponds to the main claim of the cited German patent 567,584 (Bréguét). The hub arms **60** are hinged to the rotor shaft **10** at **80**. On the arms **68** there are located the control hinge axes **35** at the outer ends of which a universal joint **12/8** is located, to which the blade spar **70** is connected. The control lever **88** of each control hinge **35** is controlled by means of swash plates **41, 48**, a push rod **43** (Figure 6) being interposed. The restricting of the flapping movement is effected by means of a lock **102** which under the action of a spring **103** tends to push in between the lips **104** of the arms **60** and thus locking the movement of the arms **60** and the hinge **86** when the speed of the rotation is low.

At higher rotational speeds, the centrifugal force will however tend to raise the weight **101**, so that the angle lever **105** causes the lock **162** to be released, a hinge part **106** being interposed. The hinges **8** and **12** may as in the case of the previously described constructional forms also be provided with adjustable or controllable stops.

It is generally desired, when starting and slowing down the rotary blades, that the upward coning angle of the blades shall as far as possible remain the same as in normal flight, and for this purpose there is according to the present invention preferably provided a system of control for the stops such that an auxiliary force, raising the blades, is imparted to the blades as the rotational speed thereof decreases. As a lifting force any known power transmission (spring force, compressed air, oil pressure, electric drive or the like) may be utilized. The source of energy may be an external source (engine, compressed air cylinder, etc.). It is however also possible to release the energy required for raising the blades from a stored centrifugal force automatically when the rotational speed decreases, so that beyond the energy required for driving the rotor no other external energy need be supplied.

Figures 45 and 46 illustrate two constructional forms of automatic blade raisers of the kind just described, in side elevation.

Figure 45 illustrates a device working by means of oil pressure and compressed air. The blade **71** is supported upon a projection **187** on the drag hinge **12** by means of a cylinder **107** which is under oil pressure and a piston **108**, and a pressure roller **184**. An oil line **109** connects the second cylinder **107** to a cylinder **111**, located near the blade tip. The cylinder **111** has a relatively small diameter and large stroke compared with the cylinder **107**. A piston **112** which is at the same time a centrifugal weight closes the oil pressure cylinder **111** tightly against a compressed air cylinder **113**. The compressed air cylinder can be filled by means of a valve **114**. In flight the piston **112** is centrifuged outwardly against the air pressure so as to impinge upon a shoulder in the cylinder, so that the said piston cannot produce an out of balance condition by its movement. The oil piston **108** is then in its upper position and releases the stop **184**, **187**. When a certain rotational speed is reached during the slowing down, the air pressure in the cylinder **113** preponderates and the piston **112** travels inwardly and presses the piston **108** down, thus causing the blade to be raised to the desired coning angle. When starting, the process is repeated in the reverse sequence.

Figure 46 illustrates a corresponding arrangement which however works purely mechanically. In this case the lifting process is produced in similar manner, except that instead of compressed air, a spring **189** serves the purpose of storing energy. Instead of the oil pressure transmission, use is made of a mechanical transmission, consisting of a push rod **193**, the rollers **115** between inclined faces, the wedge lever **116** and the pressure rollers **184**. The centrifugal weight **194** is located on the extension push rod **193**. The constructional forms illustrated are merely examples, and combinations of mechanical transmissions and compressed air storage or combinations of oil pressure transmission, and spring energy storage or the like may be used alternatively. Instead of the wedge lever **116** wedge **102** as illustrated in Figure 44 or an eccentric **95**, **96** as illustrated in Figure 42 or rollers **84**, **85** or **840/850** as illustrated in Figures 39 and 41 and 43 are also feasible in which cases also the remaining stops of the drag and control hinges may be controlled either directly or by means of remote control from the energy storing member. The use of the arrangements mentioned is also possible in the case of inclined flapping and inclined drag hinges (Figure 43) and also for a larger number of flapping hinges (Figure 44).

Instead of the controlled stops, rollers, wedges and/or stop surfaces according to the present invention use may alternatively be made of resilient substances or shapes, which allow of resilient deflection, in order that the impinging upon the stop surfaces may be as gentle as possible.

The arresting of the hinges (control hinges) which are usually movable about the blade spar axis and controlled by the pilot or automatically, may alternatively be effected by means of centrifugal stops. It is preferable to have all the stops of one blade controlled by means of the same weight.

Safety devices such as electromagnets, Bowden cables and the like may also be provided for the purpose of releasing the stops of all the rotary blades simultaneously; in the operative position these safety devices must ensure that the stops are retained in their working position.

The use of the basic idea and the details of the last described improvements is as may be seen also possible in the case of single rotors not combined in twin-rotor helicopters and in case of need they may be extended with advantage to such twin-rotor helicopters, in particular to helicopters of the constructional forms illustrated in Figures 23-30.

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