HELICOPTER RESEARCH AND DEVELOPMENT

by C G PULLIN, F R Ae S M I Mech E

Lecture given on November 9th at Manson House, Portland Place London, before Members of the Helicopter Association and Visitors from the Royal Aeronautical Society

INTRODUCTION BY THE CHAIRMAN

Ladies and Gentlemen, I feel that an introduction to our lecturer this afternoon is hardly necessary, as I am sure he is well known to most of you, but perhaps one or two may not be so well acquainted either with his background, or his work in rotating wing aircraft

Mr Pullin is the Managing Director and Chief Designer of the Cierva Autogiro Co Ltd , a Founder Member of our Association, a Fellow of the Royal Aeronautical Society, and a Member of the Institute of Mechanical Engineers He has been actively engaged in the research and development of rotary wing aircraft since 1932, but his interest in aviation goes back to pre-1914 when he learnt to fly at Brooklands in the good old days He has been engaged in engineering for about 30 years, covering in this time, several of its different branches

After the lecture, Mr Pullin will show a short film depicting various stages of test work on rotary wing aircraft, and if time permits, a short period will be devoted to answering questions Some of these Mr Pullin hopes to be able to answer here, but others may require written answers

May I take this opportunity of welcoming our guests this afternoon who, I feel sure, will be well rewarded for coming along

Mr. PULLIN —

Mr Chairman, Ladies and Gentlemen,

I must first thank the Chairman for his kind introduction, and I should also like to take this opportunity of according my appreciation of the opportunity given to me to speak before Members of the Association and visiting Members of the Royal Aeronautical Society

As some of you are aware, I have been associated with rotating wing aircraft since early in 1932, commencing of course with the Autogiro As I think I may claim to be the misguided individual mainly responsible for the first practical research and development programme of helicopters in Great Britain, I feel somewhat justified in giving a relatively brief resume of the work with which I have been entrusted over the past fourteen years

As regards the Autogiro or Rota plane, so much has been written from time to time that I propose to confine this lecture to the helicopter, but before doing so, I should like to express my appreciation of the splendid work of the late Juan de la Cierva which has enabled the helicopter to become a practical entity in the field of aviation It is also a fitting occasion to mention the valuable support given to Cierva by Mr James Weir, which put the development on a sound basis Mr Weir has also contributed many important mechanical improvements and his keen technical interest represents a monument of encouragement to all engaged in the particular " art " I must also include Mr Harold Pitcairn, who formed the Autogiro Company of America and is responsible for the introduction of rotating wing aircraft in the U S A The latest example of The Autogiro Company of America, is the helicopter built under licence by the G & A Aircraft Incorporated, branch of the Firestone Tyre & Rubber Co Inc

There appears to be a general impression that the development of the helicopter has received more attention in the U S A than in this country Whilst this may be true from the purely practical aspect, I will leave it to my audience to formulate their own opinion at the conclusion of this Meeting as to whether we have lagged behind in the scientific investigation and engineering development

The previous lecturer, Group Captain R N Liptrot, C B E , delivered a most interesting talk on the Historical Development of Helicopter Aircraft, and from which it was quite apparent that no one particular configuration could be considered as a pre-eminent solution to the problem of helicopter flight There are, for instance, many arrangements of single and multirotor helicopters in practical use today, but all employ the same fundamental principle Fortunately, as it now transpires the lift derived from the downward acceleration of a mass of air did not form the subject matter of a valid patent, with the result that this principle of direct lift is today exemplified in so many forms

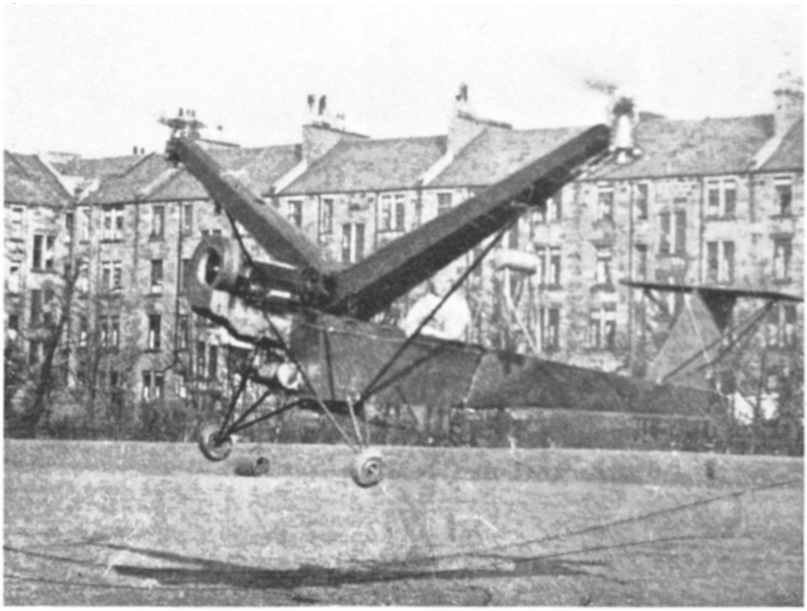
In the early days of aviation, the helicopter received much attention by scientists and inventors throughout the world, and it was soon established that no great difficulty would be experienced in obtaining substantial lift However, owing to the unsatisfactory power weight ratio of the power plant, not to mention the relatively heavy power unit installation and transmission system, the fullscale aircraft then constructed were only capable of " swimming " a few inches above the ground Subsequent development of the Internal Combustion Engine, also the use of special materials the power weight ratio of the complete aircraft was so much improved that there appeared to be adequate lift to rise some hundreds of feet from the ground Following upon this advance, the development was hampered by the state of reliability of the prime mover and transmission Here again the excellent methods of the A I D applied to the control and manufacture of aircraft engines and components, resulted in reducing this hazard to a negligible quantity Nevertheless, the potential danger still remained until the principle of auto rotation came to the rescue (thanks to the work of the late Juan de la Cierva and his Associates), which made it possible to continue the development of this most attractive form of aerial vehicle I presume it is common knowledge that in the event of mechanical failure the helicopter rotors will cease to revolve and the machine will plunge to earth in a most unsatisfactory manner By making provision for a change of blade angle to that necessary for autorotation, it becomes possible to glide safely to earth or even make a vertical descent The latter, even in the hands of a really bad pilot, would not mean more

The Weir W 5 Helicopter on the ground and in flight

than a visit to the hospital rather than a permanent one to the Cemetery. As regards the actual change of blade angle, this should be qualified by saying, that with certain projects, such as the ultra high speed rotor, it may be unnecessary to change the blade angle as the incidence for helicopter operation is of such a low order as to be suitable for that of autorotation, especially the type of helicopter blade that has a built-in wash-out of incidence as from root to tip.

From the foregoing remarks, it will be readily understood that an experimenter in the " art ", with existing data at his disposal can build a rotor to give sufficient lift for his purpose but having done so, becomes a menace to himself and to any person or persons within the vicinity of his testing ground. I am, of course, referring to the difficulties of stability and control of the aircraft when airborne.

At this stage I feel it necessary to apologise for this rather lengthy introduction, but there are I believe some fortunate members of the Association in the audience this afternoon, that have joined the development at a comparatively recent stage. In going back over the



Weir W 5 Helicopter flying backwards

past years, I realise, as one of the pioneers engaged in the development of this type of aircraft, the grave risks undertaken by Members of my Staff and also my first Test Pilot The anxiety to the Designer when the machine first leaves the ground and perhaps flies round the field for the first time, is very great Minutes seem to be as hours and the relief when the aircraft safely lands must be experienced to be fully appreciated

On one occasion in 1938, the small 50 h p side-by-side Weir W 5, inadvertently discarded a rotor blade which sailed along over the heads of the well ordered ranks of some 100 R A F recruits fortunately without damage to anything but the aerodrome and the blade itself I feel sure had Julius Caesar witnessed the occurrence knives on chariot wheels would have become obsolete Again, when testing for maximum speed, which by the way was in the order of 70 m p h , the pilot attempted a banked turn at the end of the straight run but instead the aircraft decided to make a power-dive from 150 feet The pilot operated every available control to pull the machine out before it hit the ground but his efforts being unsuccessful, resigned to await the unwanted but very necessary bump To his surprise, and to the amazement of the few onlookers, the aircraft appeared to take advantage of the ground cushion effect straightening out into a nice flat glide across the field

On another occasion, when demonstrating the flying capabilities of the same machine, the tail wheel and oleo dropped off when on the fifth circuit of the football field at some 200 feet from the ground

Weir W 6 Helicopter in flight.

The pilot was quite unaware that he had lost what would once have been considered as quite an important part of the aircraft, finally making the usual soft helicopter touchdown but at a silghtly increased ground angle to that for which the machine had been designed. With the larger edition of the same type, i.e., the Weir W 6, whilst hovering some 50 feet from the ground one of the rotor blades broke away at the root end which incidentally caused much perturbation as the factor of safety was considered to be adequate.

The pilot and his passenger on this occasion made a wonderful tail slide landing, being finally ejected through the bottom of the fuselage. I believe the marks of their passage through the machine are in existence today, but not of course, on the airfield.

As a point of interest I might mention that the Test Pilot's licence was subsequently endorsed for helicopter flight and it may therefore be put on record that outside of Germany he was, I believe the first officially recognised helicopter pilot.

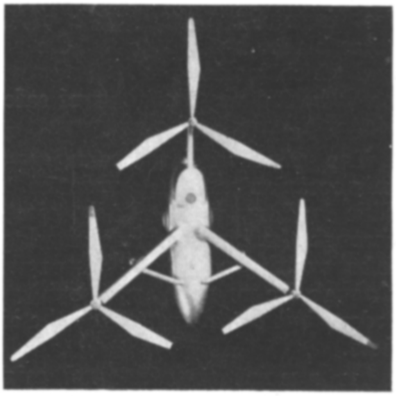
In conclusion of this introduction and before I proceed with perhaps some of the more interesting details of development I must apologise for being unable to exhibit any colourful films of flight testing or demonstrations, but on the other hand, most of the slides that will be shown on the screen, have in their development, merited the colourful remarks of those engaged in their conception and practical application.

5 Weir W 6 Helicopter in flight with Lord Tedder as passenger (1940)

I will deal with the subject which seems to be pre-eminent in the minds of those associated with the " art " either as inventors, designers or practical operators. I refer to the problem of torque balance. In discussing a new helicopter project the first question asked is what method is employed for torque balance? Why so much attention is focussed on this is rather curious, as the engine power expended for instance with the tail airscrew or even tail jet, is quite marginal. The interest perhaps is associated with the remote possibility of securing torque balance by some inceptive influence outside the aircraft or by a cunning arrangement of components to achieve the desired results at zero cost. A great number of ingenious schemes have been proposed some even in practical form, but no satisfactory solution has been found apart from the generally known and accepted examples as in use today As most of you are aware, the necessity of torque balance is substantially eliminated by the use of multi-rotors, whether side-by-side, co-axial or star plan configuration It will also be understood, that in the case of the Autogiro, the rotor being self driving under aerodynamic influence, does not produce any reaction in the body of the aircraft about the rotor or yawing axis The same may be said of the helicopter rotor propelled by reactive thrusts from jets or slots formed in the rotor blades Strange as it may seem, my recent experiments indicate that the complete elimination of rotor torque reaction is inadvisable which will be gathered from particulars of tests to be described later

In 1937, I proposed to the Directors of Messrs G & J Weir Ltd, licencees of the Cierva Autogiro Co Ltd, that the Autogiro development work with which I was entrusted, should be extended to the helicopter The German Company of Focke Aghelis, licencees of the Cierva Autogiro Co Ltd were, at that juncture, making practical tests of a twin rotor, side-by-side helicopter At the request of the Ministry of Aircraft Production, an endeavour was made to secure a duplicate machine for experimental tests in this country but the price was prohibitive and delivery somewhat protracted At my suggestion, Messrs G & J Weir, Ltd, agreed to build a research helicopter and I received instructions to investigate the possibilities late in 1937 The first study was concentrated upon the two rotor superimposed arrangement, but the then apparent difficulties of securing unhampered blade articulation or let us say fouling of rotor blades, appeared to be very severe Control and stability problems were the main reason why the project was discarded It will be noted that I evaded the difficulties of torque balance by the oppositely turning superimposed rotors Having realised that the major problem was one of control and stability, the obvious solution was to place the rotors on either side of the fuselage Turning in opposite sense would deal with the question of torque balance, so that control and stability could be studied in a more appropriate manner

As I am now dealing with the subject of torque balance, which if not eliminated completely, is simplified by the use of multi-rotors, it would perhaps be fitting to briefly examine such types There are many possible arrangements of multi-rotor helicopters and it is obvious that the twin side-by-side type can be re-arranged so that the rotors are fore and aft, i e the tandem arrangement



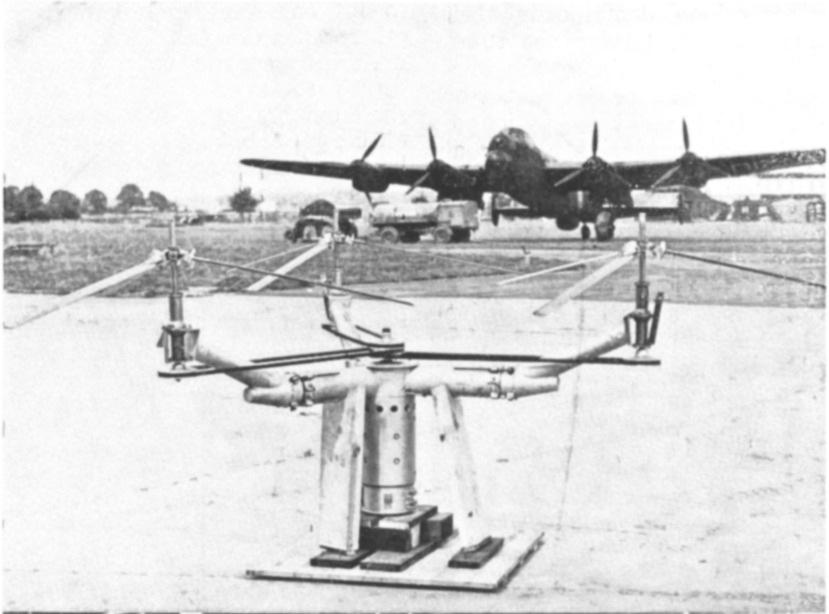
6 *Cierva two engine three rotor ten passenger or freight helicopter*

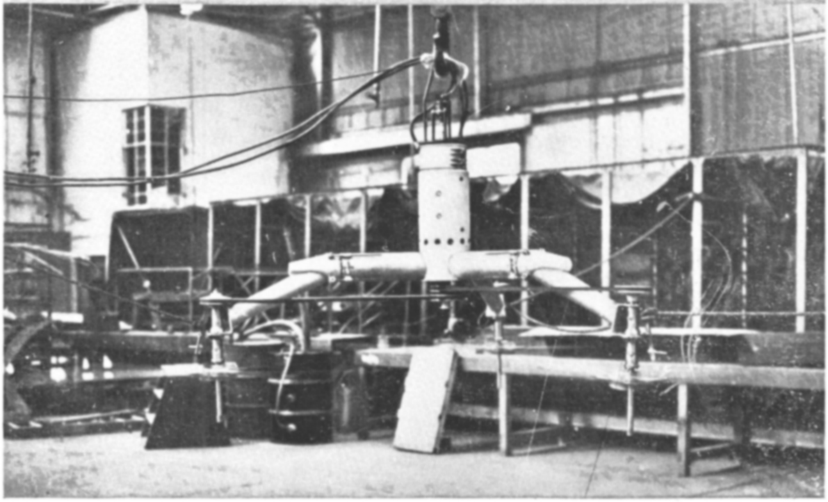
Then again we may use three rotors, the plan form geometry giving a relative spacing of the rotors of 120 degrees This incidentally, becomes interesting, because it is possible to have two of the rotors turning in opposite directions and thus cancelling domestically their torque reaction, leaving one rotor or let us say one third of the total torque, to be balanced This can be achieved by a slight inclination of the rotor axis producing a force at right angles to the lift to balance the torque A further possibility is to have all three rotors turning in the same sense, dealing with a resultant torque reaction by a slight tilting of the rotor axes against the direction of the torque reaction This proposal I have adopted for the three rotor helicopter to be known as the ' Air Horse ' and now under construction by the Cierva Autogiro Co Ltd With this arrangement there are of course, a number of apparent advantages, the chief perhaps being the constructional gain arising from the interchangeability of rotor blades rotor hub components, etc This is quite an important feature when considering service and maintenance, apart from reduced cost of production especially where jigs tools and moulds, as for the rotor blades, are involved There is also an indication that, purely from the stability angle, the three rotors turning in the same sense, gives the optimum arrangement

Powered model tests now in hand are confirming such contentions

Before turning to the single rotor machine, I would like to emphasise an important point although it is purely a secondary effect When the axis of a rotor is inclined from the vertical, we get a resultant torque reaction about the rotor axis As a simple explanation, we might take the case of a normal fixed wing aircraft fitted with an airscrew in the nose of the machine

When the airscrew is running there is a torque reaction in the opposite sense around the longitudinal axis of the machine This tends to lift one wing and depress the other a feature well known to aircraft designers and pilots If we now turn the axis of the engine crankshaft through 90 degrees so that the airscrew is above the fuselage, we have, of course, an arrangement similar to that of the helicopter The torque reaction is now present in the fuselage about the yawing axis Let us now choose a position for our engine crankshaft axis 45 degrees from the horizontal The torque reaction is consequently divided between the yawing and rolling axes From this it will be understood that if we take a normal helicopter and incline our rotor axis in a forward direction, also assuming the rotor is turning in an anti-clockwise direction looked at from underneath, there will be a residual torque reaction tending to roll the machine to port On the other hand, should the rotor axis be tilted to port then the residual torque reaction will tend to raise the nose of the aircraft This is a very important effect and introduces many practical difficulties in stability and control I have mentioned this phenomena as some designs have been proposed and are in the course of being built with the rotor axes set in inclined positions The secondaries arising from such an arrangement must be given every consideration No doubt you are aware of the close meshed side-by-side rotor arrangement, originally proposed by the Cierva Autogiro Co , Ltd , and subsequently made by Flettner in Germany and Kellett in the U S A In this case even the small included angle between the rotor axes introduces difficulties with control and stability





7 *Three rotor wind tunnel model powered by 28 h p electric motor as tested at R A E Farnborough*

8 *The same model inverted as run in the tunnel*

In the single rotor class helicopter, I will at first refer to the type put into practical operation by Igor Sikorsky I should like to pay tribute to Sikorsky's work, mainly in connection with the practical application of the helicopter and the tail rotor system of torque balance in particular It was, of course, proposed many years ago and decried by some engineers who suggested that it was impossible to balance a moment by a couple This, of course, is true, but is not the end of the story Placing a small rotor some distance from the main rotor axis, i e at the tail end of the fuselage, does not in itself balance the torque as we are left with a force in a lateral sense, which in turn must be balanced by tilting the rotor axis so as to introduce an equal force in an opposite direction When this is done and assuming the aircraft is airborne, it may be said that the machine is now constrained in aerodynamic equilibrium Any change in the value of the constraining influences such as those arising from an alteration of mass trim of the aircraft or by wind differentials, necessitates a re-adjustment of the balancing forces or in other words application of control With the time at my disposal I shall not be able to adequately deal with other possible methods of torque balance of the single rotor machine which are of sufficient importance to warrant comprehensive treatise, but I will mention some of the work of the Cierva Autogiro Co Ltd , that has been carried through under my direction in recent years I will refer to

(1) The paddle wheel type of tail rotor, which when fitted with cyclic and collective pitch can give a directed thrust reaction for the purpose of control about the yawing and pitching axes For reference I quote the Voith System of Propulsion

(2) Torque balance by means of two tail rotors having their axes inclined in an appropriate manner to give a similar effect to the paddle wheel

(3) A tail rotor capable of having its axis turned through 220 degrees in the plane of azimuth

(4) A tail rotor with a fixed inclination of its axis in some specified direction to eliminate some of the difficulties associated with forward speed of the aircraft

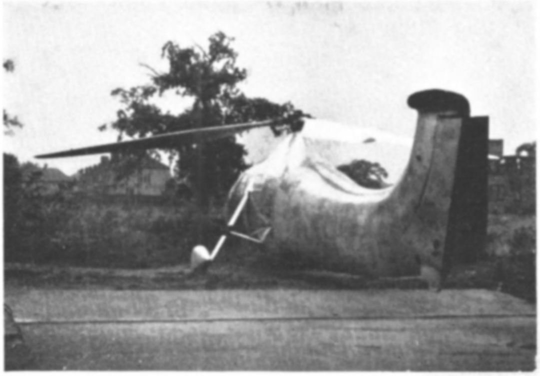
As my time is limited, I will conclude the subject of torque balance by referring to the Cierva Company's research helicopter W 9

Here torque balance is achieved by reactive thrust from a jet located at the tail end of the fuselage During the last two years practical tests may be considered as very satisfactory

Torque balance and yawing control is adequate and the system particularly smooth throughout the speed range Service and maintenance has been cut to a negligible amount also a reduction of constructional weight is gained

Ground handling is of course greatly improved and the ability to make the approved form of Autogiro landing is particularly useful Rapid deceleration when flying as a helicopter near the ground is also possible as there is no tail rotor to protect and the aircraft can be landed tail wheel first or in the case of a nose wheel the tail skid or bumper may be used

An additional and very important advantage is the accommodation of longitudinal shift of the c g by means of the tail jet deflectors Control of the deflectors produces a



10 *Cierva W 9 as tested in October 1944*

11 *Cierva W 9 in flight at Henley 1945*

9 *Cierva W 9 as tested in October 1944*

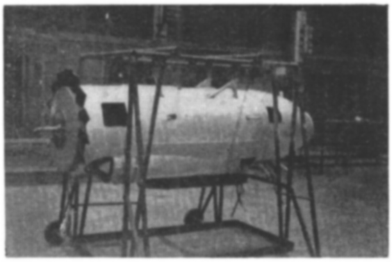
16 *Cierva W 9 centre section showing enclosed engine installation*

12 *Cierva W 9 in flight at Southampton Airport*

13 *Cierva W 9 in flight at Radlett S B A C display (Note tail fin)*

C

component force to raise or depress the tail of the machine at will This in conjunction with an *appropriate* system of rotor control, eliminates the necessity of flying the aircraft on attitude, i e the fuselage can remain on an even keel during acceleration from hovering, when decelerating or during forward speed



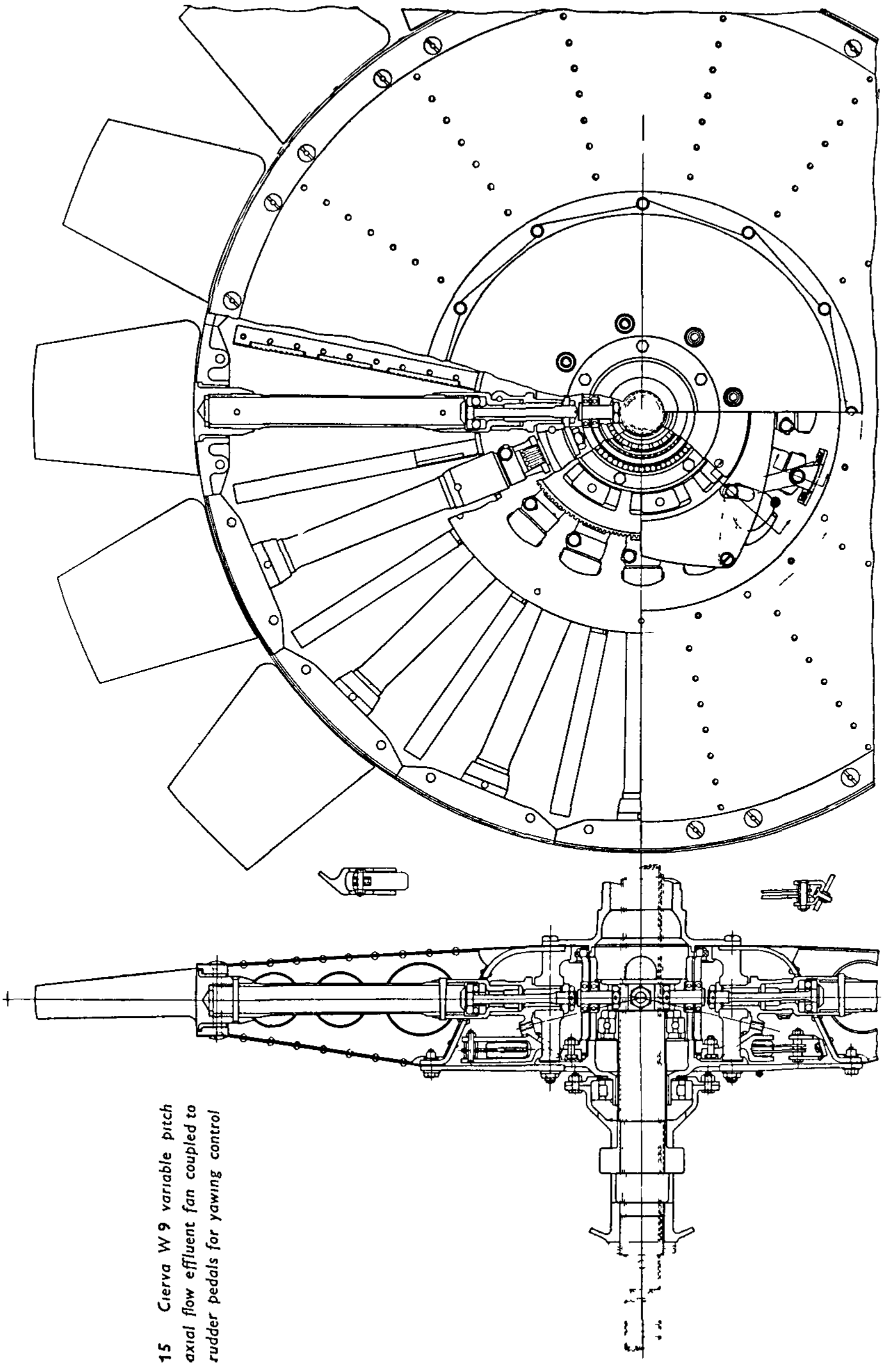
14 *Cierva W 9 Gipsy engine unit* (200 *h p*)

This jet system, when subjected to the merciless guillotine of the mathematician appears very uneconomical but proper evaluation can only be established when all the accompanying advantages are placed in the scale pan Owing to the relatively high velocity of the effluent about 150 ft /sec the loss of kinetic energy is greatly in excess of that of the low velocity slip stream of the small tail rotor To balance this, the heat dissipated by the engine cylinders and exhaust gasses is utilised, admittedly at low thermal efficiency, to increase the reactive thrust with a consequent reduction of the fan h p As some 65 per cent of our fuel energy is wasted in the cooling system and exhaust gasses we can, even at low efficiency, regain some useful horse power or its equivalent In the case of W 9, when hovering, this amounts to approximately 9 h p the heat, of course, increasing the velocity of the effluent at the jet

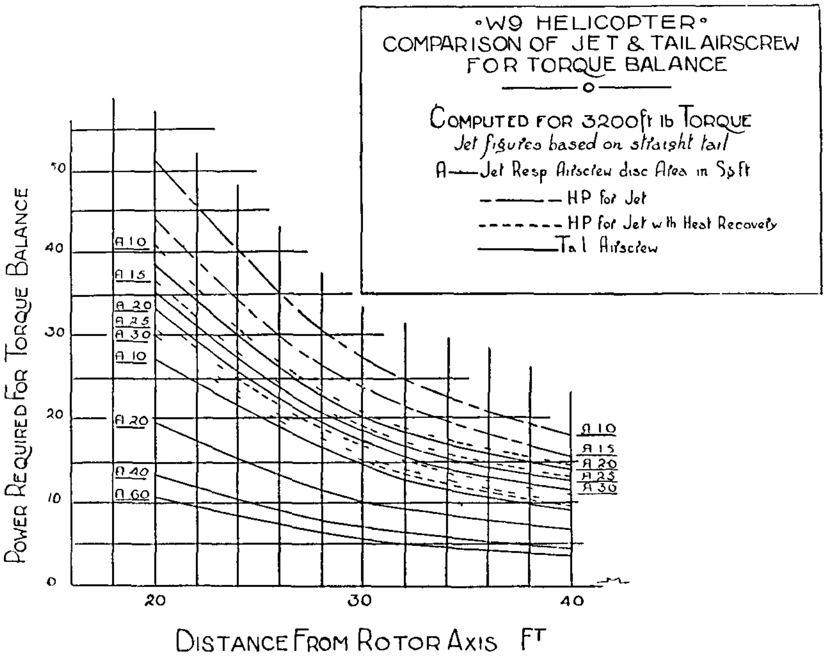
It is important to understand that the heat is added after compression of air by the effluent fan, which operates in this case at pressure datum of approximately 35 lbs above atmospheric pressure

Assuming the appropriate tail rotor was fitted to this machine, in hovering the jet system would require an additional 2 5 h p , which translated into terms of lift on the machine in question, at say one rotor diameter from the ground, would represent some 42½ lbs This, incidentally, would be more than saved in constructional weight At cruising speed the effluent fan, having variable pitch blades, is feathered so that the aerodynamic rudder and directional properties of the fuselage are in action, the resultant drag being equivalent to approximately 2 3 per cent of the h p required for the cruising condition

It may be appropriate to introduce at this juncture, the advantages and disadvantages of gearing the tail rotor to the main rotor It is admitted that in an emergency vertical descent the tail rotor gives control about the yawing axis which is most important if the machine is to be positioned correctly especially if drift is present prior to landing On the other hand, the tail rotor is equivalent to a brake on the main rotor and is to some extent responsible for the high rate of vertical descent of some of the helicopter aircraft now in use It may be argued that the tail rotor blades when set at zero pitch will not take any appreciable power from the main rotor Even the windage of the feathered tail rotor produces a torque reaction about the rotor axis so that some pitch is required to effect balance about the yawing axis A figure of 3 5 h p has been calculated for a given machine and



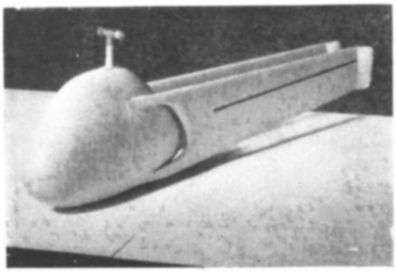
15 *Cierva W 9 variable pitch axial flow effluent fan coupled to rudder pedals for yawing control*



the equivalent braking torque is thus applied to the sensitive autorotating rotor I have neglected the gliding case with the tail rotor positioned for autorotative effect

In the case of W 9, the free wheel is in the rotor hub so that the effluent fan becomes inoperative during an emergency landing under autorotative conditions Intentional autorotation can be enjoyed as the pitch range of the fan blades permit even a slight reversal of the flow at the jet orifice In pure vertical descent, as say from 80 feet, the aerodynamic rudder of W 9 would be substantially inoperative The aircraft is consequently fitted with a final positioning device in the form of two fluid jets connected with a small accumulator charged to a pressure of 3000 lbs/sq in The jets are brought into action by an emergency button but under the control of the normal rudder pedals A supply of one gallon of fluid is sufficient for the requirements and lasting some 10 seconds and at a rate of vertical descent of say 40 ft /sec , we have sufficient yawing control as from 400 feet above the ground The total weight of the apparatus is less than 20 lbs On this particular machine the hydraulic components, including the fluid, are already available as part of the servo rotor control system

In spite of the shortness of time at my disposal, I feel I should say a few words regarding torque balance by means of aerodynamic surfaces located in the slip stream of the rotor The calculations as to the amount of surface required are comparatively easy when the slip stream velocity is known On the score of efficiency this velocity will be of a relatively low order, and in the experiments I have in mind was within the region of 40 ft /sec The location of the aerodynamic surfaces in relation to the rotor is not so easy, it being very difficult to establish the axial distance from the plane of the rotor where the slip stream is fully developed I understand that full scale tests had been conducted by Haffner, Focke, Platt and others, but I was determined to carry out a theoretical and practical investigation, the latter in model form, to ascertain as to whether the method represented a possible solution



17 *Wind tunnel model of torque balance project having adjustable surfaces located in rotor slip stream*

The model constructed for test is that shown on the screen, but was first designed to have only one surface which should have been ample for the purpose, the duplication being added subsequently For the purpose of convenience, the actual rotor with articulated blades was mounted on the driving shaft of an electric motor, the fuselage being suspended underneath on anti-friction bearings to permit freedom about the yawing axis A single horizontal hinge allowed the model to turn about the pitching axis, the whole being supported in the wind tunnel Moments about the yawing and pitching axis could be taken whilst under the influence of the rotor slip stream Sufficient freedom was also available to allow the model of the fuselage to rotate through 360 degrees in azimuth The floor of the tunnel was adjustable from two rotor diameters from the plane of the rotor to within a quarter of the rotor diameter To describe the full details of the test is beyond the scope of this meeting, but I am sorry to say the results were most disappointing Briefly, it appeared that when the complete model was free to enjoy full symetrical rotor circulation, the aerodynamic surfaces could be adjusted to balance the torque reaction, the torque moment of the model being checked against the torque reaction of the motor casing As soon as the adjustable floor was brought within one rotor diameter of the plane of the rotor, strange things began to happen, the torque reaction became unbalanced and on one occasion was over determined Even a rectangular hole in the wall of the tunnel some 15 in square to accommodate the balance arm of the model would, when the fuselage was free to spin, create an effect sufficient to momentarily arrest the model for 1 to 2 seconds As a point of interest, the area of the aerodynamic surfaces in relation to the disc area was, in the case of the single surface, some 7 15% and when duplicated 14 3% I am not suggesting that it is impossible to eventually reach a solution by this approach, although I am very doubtful whether precision flying near the ground would be possible The German Dublhoff helicopter with jet reaction from the blade tips and employing aerodynamic surfaces for yawing control only, was shown on the screen during Captain Liptrot s lecture The erratic displacement of the aircraft when a few feet from the ground confirmed in full scale the tests I conducted in the wind tunnel I understand that Dublhoff's latest helicopter has discarded the aerodynamic surfaces for a tail rotor driven from the main rotor, purely for the purpose of adequate control about the yawing axis during hovering and when in slow translational flight

To conclude this brief resume of torque balance, it now appears, that if we completely eliminate torque reaction in the body of the aircraft, we have lost control about the yawing axis when hovering or flying close to the ground It thus becomes necessary to provide mechanical means for yawing control, as for instance in the form of a small tail rotor or fan A further important point is the effect on stability and control, which will be dealt with later

Rotor Blade Mounting

This may be divided as follows —

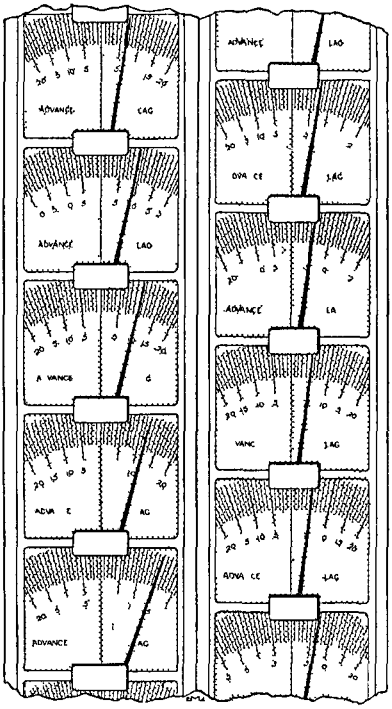
1 Non articulated rotor blades, commonly called the rigid rotor which of course is a misnomer
2 Fully articulated rotor blades

We find many combinations in use to-day and from my experience I am in favour of the fully articulated rotor blade system In connection with this, it must be understood that the rotor blade or blades must be *fully articulated* under all airborne conditions The only time that one degree of freedom may be lost is during the initial stage of starting the rotor, when of course, the blades will lag on to the back stops There is a definite reason for this requirement of free articulation and although it may be said the helicopter is incapable of being stalled in the same manner as a fixed wing aircraft, nevertheless, it is possible to stall the rotor under certain conditions of helicopter and Autogiro flight This would mainly be attributed to an error of pilotage or lack of appreciation of the necessary blade pitch or angle of incidence to deal with intentional or emergency cases I wish particularly, to refer to individual blade stalling brought about by a concatenation of circumstances, which would normally cause a blade or blades to stall With the freely articulated blade this can be avoided by the upward flapping movement giving a virtual reduction of blade incidence and thanks to its curvilinear path is soon out of immediate danger This, I believe, is termed by our American friends as "sailing" of the rotor blade The required freedom is quite considerable and a lack of appreciation of this requirement was responsible for the loss of the rotor blades on my early experiments with helicopters W 5 and W 6 In both instances drag and flapping freedom was approximately half of that necessary to meet the conditions In the case of a three bladed rotor, if one blade becomes stalled the inertia torque of the other two blades is of such magnitude as to cause the stalling blade to break, either at the root end or approximately at half the blade radius, unless it is free to "sail" about its articulated restraint I have recent evidence of helicopter blades that have been forced against the top flapping stops indicating a vertical flapping displacement of the blade or blades of over 37° from the horizontal Knowing all the relevant parameters and taking the coning angle as 6° it is possible to evaluate the kinematics and the resultant portent

With such large orders of flapping displacement an examination of the control mechanism is advisable If we take the usual blade control arm mounted near the root end of the blade and assuming the upward flapping displacement was 90°, then the swash plate control mechanism becomes inoperative Even at 37° displacement the effect becomes apparent It is for this reason that

I favour the internal blade control mechanism of the Weir helicopter W 6

In the case of the non articulated rotor blade, we find, that should conditions arise to promote an incipient stall, then the blade is unable to ' sail " so as to virtually reduce its incidence The incipient stage is followed by the full stall on account of the inertia torque of the remaining blade or blades To make the blades sufficiently robust at the root end becomes uneconomical, and even so, the point of fracture will be moved along the blade towards the tip but is likely to occur at about 6 of the blade radius If we endeavour to increase the strength of the blade at this point we run into difficulties from the aerodynamic aspect



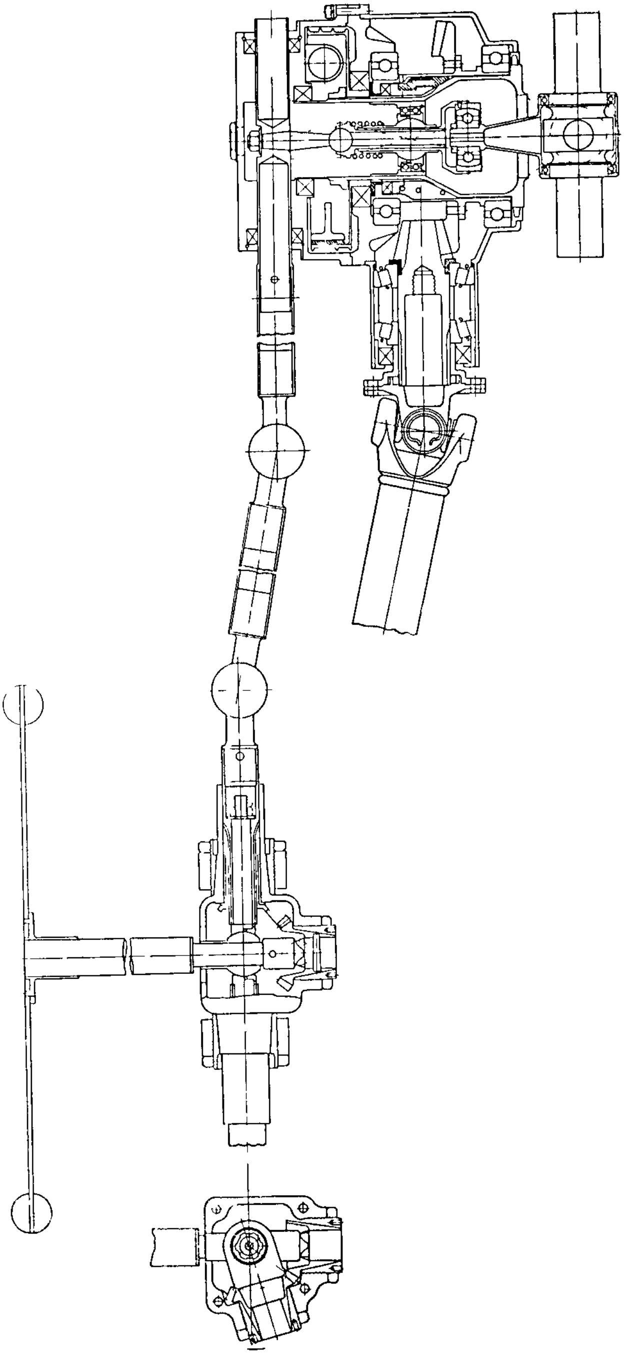
19 *Film cut of rotor blade displacement to check blade kinematics*

The use of non articulated blades attached to an unarticulated rotor hub is, of course, only permissible on multi-rotor machines when the rotors can be arranged to turn in the opposite sense to domestically cancel out the gyroscopic moments Vertical bending loads also bending in the plane of azimuth can be reduced by building-in of the mean coning and drag angles On the other hand, a modified arrangement of non articulated rotor blades is that wherein the blades are secured to an orientable hub or gimbal component This eliminates the gyroscopic moments from the machine but differential blade flapping is prohibited In turn we get disc flapping or tilting of the rotor disc which can be under control of a swash plate or cyclic pitch, or by cross pin constraint as is the case of the orientable hub Unfortunately, either arrangement does not permit of blade " sailing " and in my opinion is undesirable In talking of articulated and non articulated rotor blades I am excluding the torsional pitch change hinge which performs the separate functions of cyclic and collective pitch

I have found that some rotor systems will behave perfectly for many hours of hovering and normal flight until a particular set of circumstances arise which are beyond the capabilities of the system Such circumstances may be due to one of or any combination of the following —

1 Gust effect causing a considerable displacement of the aircraft about the rolling, pitching and yawing axes or interrelated effect

2 Change of angle of attack of the relative wind by as much as 90°



20 Weir W 5 rotor hub and control organs

3 Mis-application of control in correcting numbers 2 or 3

4 Dissymetrical rotor circulation

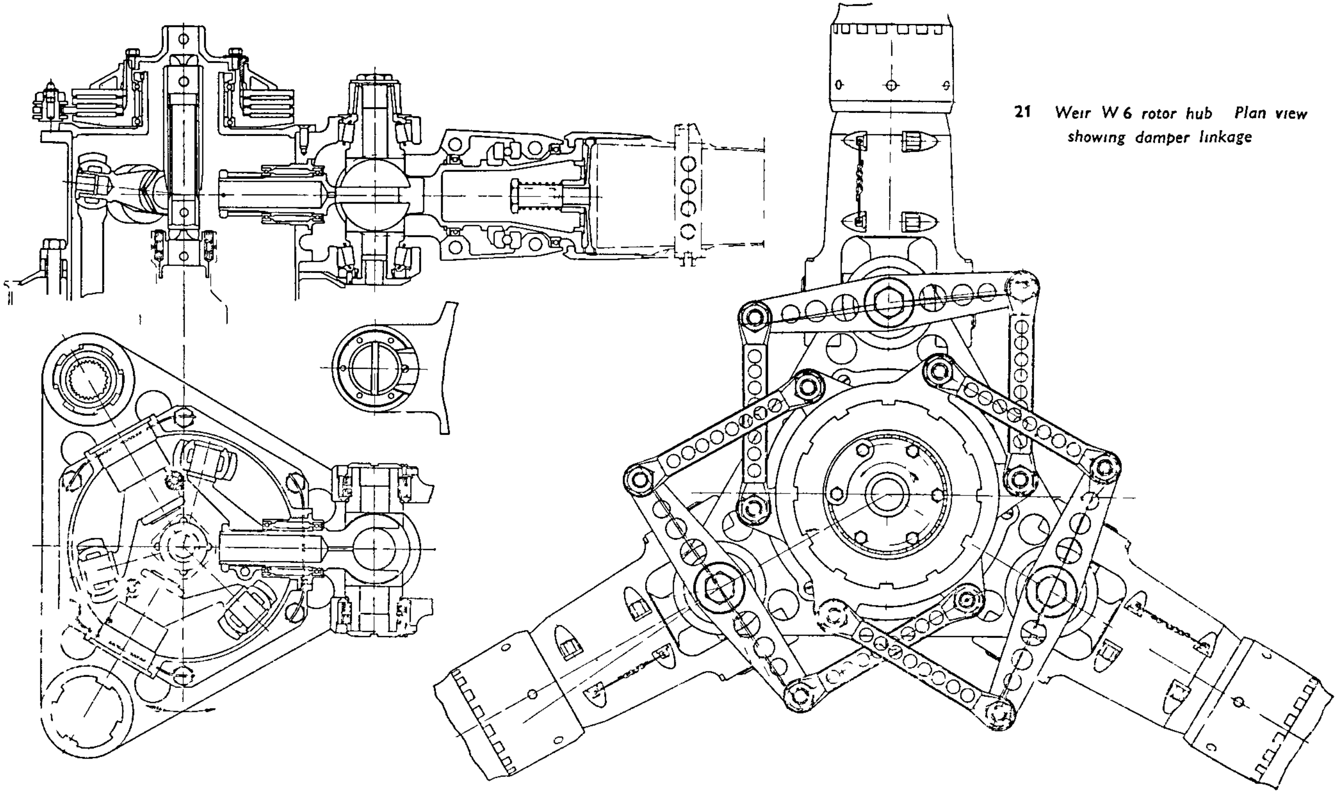
Although the foregoing remarks mainly apply to the helicopter, it is also possible, under certain circumstances, to run into trouble by overdoing a flared-out landing under conditions of autorotation This was not the case with the old Autogiro as the control range was strictly limited and the drag and flapping stop clearance commensurate with the requirements but at the cost of limited control range

Rotor Systems

During the last 14 years I have been responsible for, and associated with, many designs of full scale rotor systems also a large number of working wind tunnel models As a matter of fact, it would be difficult to suggest an arrangement that has not been fully investigated both on paper and in some practical form or another My early work was confined to the orientable direct control Autogiro rotor systems which also included the jump start Autogiros, which were of course helicopters during the period of direct take-off The many years' experience with the orientable rotor hub brought to light the advantages and also the limitations of this system, the latter being of such magnitude that I considered the most appropriate method for the control of the helicopter was that of cyclic pitch This system was adopted for Britain's first successful helicopter, the Weir W 5

Cyclic pitch was also used on its successor, the Weir W 6, but I reverted to the orientable rotor hub for the Cierva helicopter W 9 Some explanation is perhaps necessary

It has been shown by Locke Wheatley and others, that cyclic change of the blade pitch is equivalent to sinusoidal flapping for the purpose of equalising the lift round the disc, as is necessary in forward flight or when hovering in gusty weather Whilst this is true, we find a marked difference in the two systems Let us assume that our aircraft is hovering in still air and we incline our control column to effect forward translation In the case of the orientable hub, we tilt the tip path plane of the rotor or let us say disc, and the resultant translational force commences to accelerate the machine During the initial period of acceleration the rotor remains in symmetry and is consequently smooth or vibrationless As our forward speed increases, the differential flow will in turn produce differential flapping of the rotor blades and the aircraft will become progressively rougher in relation to the translational speed The lift vector of the rotor will now be tilted back the machine tending to climb unless the control column is pushed forward, so that the limit of forward control range is quickly reached To deal with this unhappy state it is necessary to employ means to suppress the flapping or alternatively tilt the rotor forward by changing the attitude of the fuselage, thereby regaining some of the forward control range Now with the cyclic pitch control system when the control column is moved forward to accelerate as from the hovering condition we immediately introduce differential flapping and the aircraft becomes quite rough This roughness will persist if we attempt to keep the fuselage on say an even keel, so that to enjoy reasonably smooth translational flight the rotor disc must be tilted which, of course, is directly associated with the attitude of the fuselage By the correct co-ordination of throttle, aircraft attitude, and application of cyclic pitch, we can reach an optimum speed at which the aircraft remains reasonably smooth



21 *Weir W 6 rotor hub Plan view showing damper linkage*

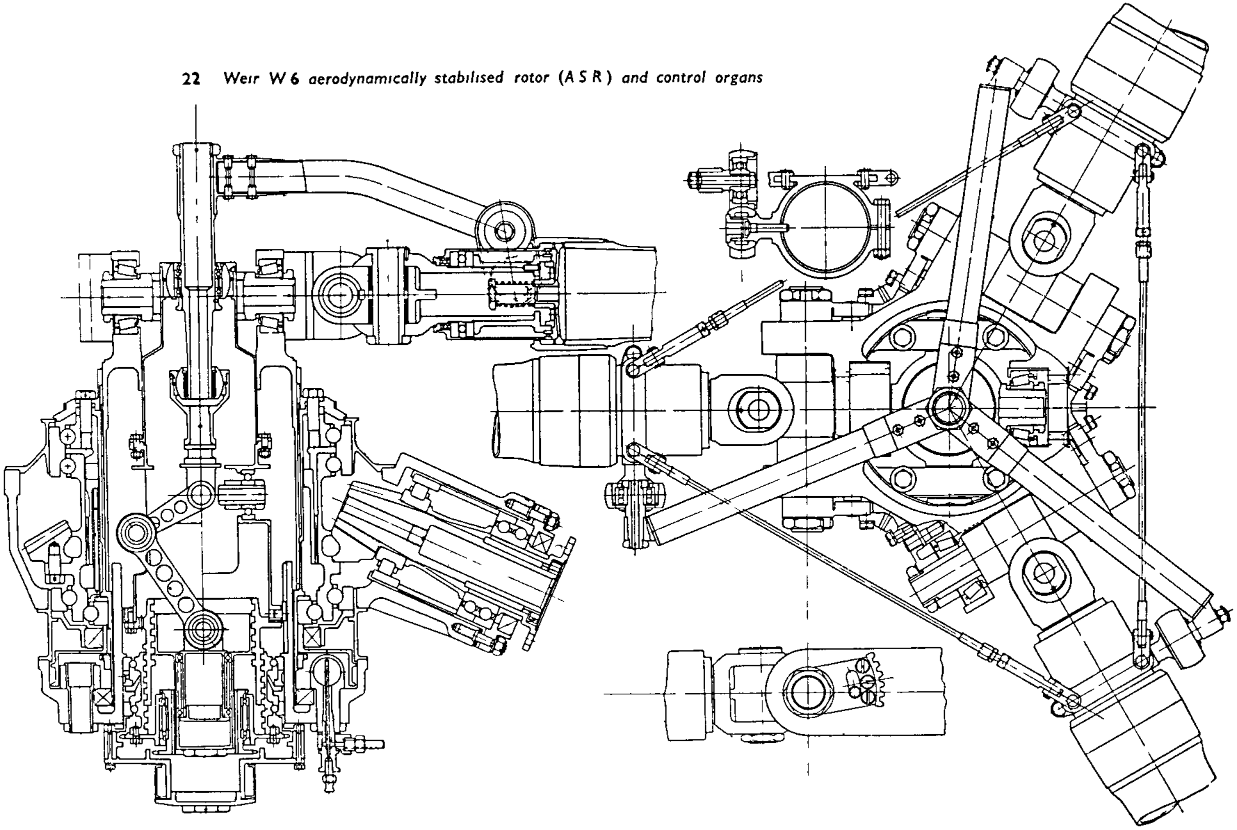
It is thus obvious that one of the difficulties with the orientable hub is that of the suppression of flapping A Delta III effect or pitch change coupled with flapping displacement was embodied in a rotor system termed the A S R and tested in full-scale on helicopter W 6

The results were very promising but the experiments were curtailed owing to the turn of the war in July, 1940 In this system, the three rotor blades were attached to a hub which in turn was mounted on a gimbal component The rotor blades were provided with drag and flapping hinges but bridled in such a manner as to permit of coning of the three blades but suppressing the differential flapping Arms from the blade torsion hinges were under control of a swash plate mechanism so that the rotor disc always followed the inclination of the swash plate It will be understood that as differential flapping was suppressed, the rotor as a whole was constrained to flap or tilt about the gimbal component Gust effect or differential flow would cause the disc to tilt about the gimbal component whereas the swash plate datum remained fixed This in effect reduced the blade pitch in a cyclic manner and was substantially equivalent to a control effect on the part of the pilot Unfortunately the rotor or disc tilt of this system has a precessional characteristic and whilst this is cancelled out domestically on a multi-rotor machine, I do not recommend its application to single rotor machines

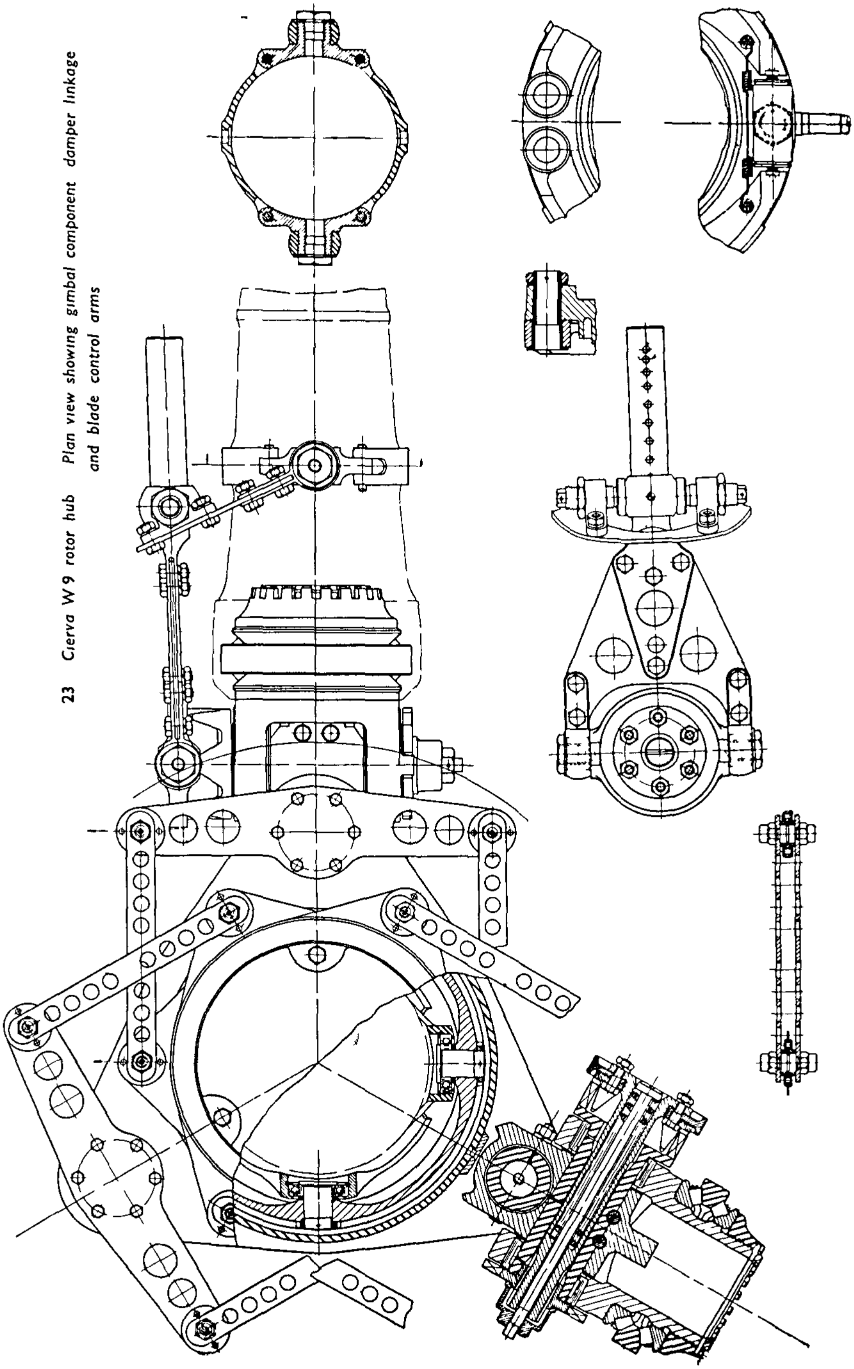
As my experiments with cyclic pitch control were substantially completed in 1940, it was agreed that no immediate useful purpose would be gained by making, at that juncture, some practical examples for operational duties but an endeavour should be made to develop the A S R system which, in spite of certain limitations, had displayed practical advantages An elegant solution appeared possible with the orientable hub arranged with a large order of Delta III Wind tunnel model tests of this project indicated the possibility of a self incidence setting rotor close to the optimum of that suitable to helicopter operation together with an automatic changeover to the optimum setting for autorotation A full-scale rotor was not completed until 1944, and when tested, immediate difficulties were experienced with the control

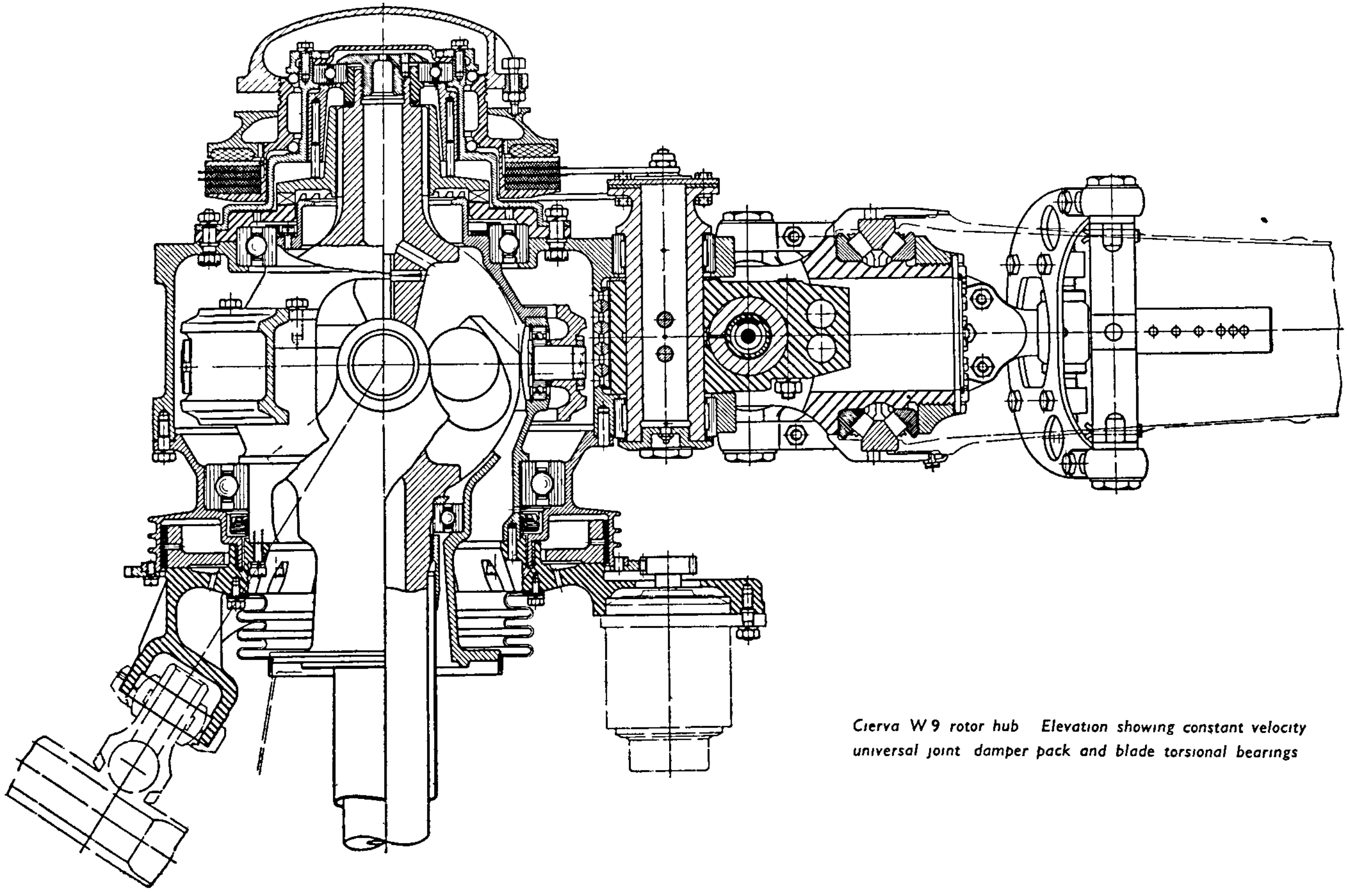
A careful investigation traced the trouble to control phase and although the machine was hovered for a considerable number of hours, full control was not gained until the Delta III had been back coupled as from one blade to the other to thus correct the phase and in accordance with the value of the Delta III in use To clarify this, the flapping displacement of one blade would change the incidence of the following blade and so on with the other blades This system has proved quite successful in test and is very smooth throughout the speed range On the other hand, it has been necessary to speed up the rate of control application by means of a hydraulic servo mechanism to give the instantaneous response necessary to check the displacement of the aircraft The range of angular tilt of the hub is also excessive Although the system may be considered as adequate to meet all the requirements of normal flying, it falls short of certain essential qualities for precision flying close to the ground This is mainly due to the fact that the rotor spills off any excess lift, the lift being in accordance with the value of omega or let us say rotor r p m With unlimited power at our disposal we could get sufficient acceleration of the rotor to deal with the rapid

22 Weir W 6 *aerodynamically stabilised rotor (A S R) and control organs*



23 Cierva W 9 rotor hub Plan view showing gimbal component damper linkage and blade control arms





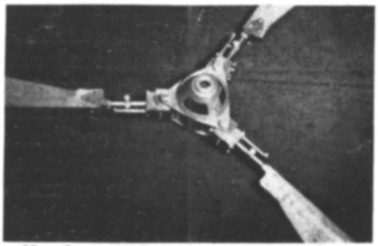
Cierva W 9 rotor hub   Elevation showing constant velocity universal joint damper pack and blade torsional bearings alteration or variations of height when close to the ground but in practice, as the reserve power is somewhat limited, it seems expedient to take advantage of the kinetic energy stored in the rotor By the use of collective pitch it is possible to use the stored energy to meet the exacting requirements of the case mentioned

Having thoroughly explored both the cyclic and collective pitch control systems also the plain orientable hub and in conjunction with Delta III effect I am now able to propose a combination arrangement escaping the limitations of both systems but retaining the good features of each Unfortunately, it is not possible, at this juncture to release any relevant information but it is hoped that the wind tunnel model now on test will be represented in full-scale on the Cierva W 9 research machine by the end of the year or shortly afterwards

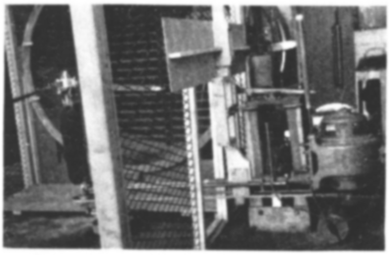
It will be appreciated that I could take up a great deal of time in describing my work with various rotor systems, so in the circumstances I must now turn to the next item, i e , Rotor Blades

Rotor Blades

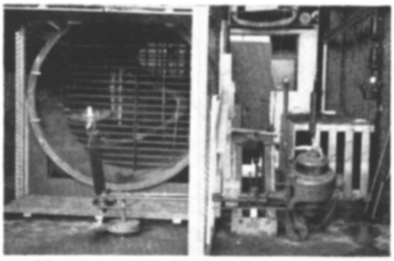
Under this heading, we have perhaps the most important component of the helicopter aircraft, involving the usual conflict of aerodynamic requirements and constructional limitations I should qualify this by saying that great care must be paid to the design if reasonable efficiency is to be achieved Some helicopters that have flown and are still in use, show lift efficiences of quite a low order, being in the region of 60% as against some 82% that is possible by careful choice of the major parameters Unfortunately, the ideal aerodynamic requirements introduce structural limitations so that the ultimate choice is that of compromise The desired blade kinematics in forward flight and when the rotor is under the influence of the control column, as in the hovering state, are only possible if the blade construction is such as to permit the blades to react correctly to the pilot's control Let us take a rotor blade mounted on its hub component through the medium of drag and flapping hinges, also a torsion hinge so that the blade may be controlled in pitch by suitable mechanism as for instance a swash plate under



25 *Cierva W 9 wind tunnel model of new Delta III rotor hub*

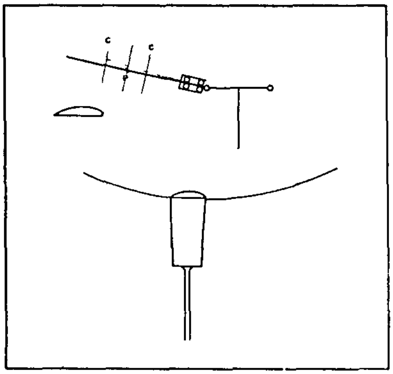


26 *Cierva W 9 model hub mounted in the wind tunnel*



27 *Cierva W 9 Delta III hub on test in the wind tunnel*

influence of the pilot's control column If the blade in question is very flexible in the torsional sense and unless we arrange our mass distribution in an appropriate manner, it will be found, that the application of the pilot's control to the root end of the blade will fail to be communicated to the tip end or to the region where the change of incidence is most effective A further difficulty arises from bending of the blade in the vertical sense as by the application of control by turning the blade about the torsion hinge the outer portion, particularly the blade tip, will describe an arc, the radius of which will depend on the amount of bending



28 *Diagrammatic sketch relating to periodic bending of rotor blade*

If it is possible to reduce the bending to zero, the blade will, of course, turn about its longitudinal axis Quite severe moments can be present in the control column unless the bending is kept to a very low order It will also be realised that in translational flight or under gust conditions, the effect of differential flow will introduce an excursion of the centre of aerodynamic pressure in relation to the centre of percussion of the blade Under these conditions we have a periodic bending of the outer portion of the blade corresponding to the movement of the centre of pressure in relation to the centre of percussion, so that the outer portion of the blade is subject to upward bending over one half of its path round the disc and downward bending over the other half I will not deal with the attendant difficulties, but when associated with relatively flexible blades the application of control or gust effect may introduce some serious problems and the practical results can be disastrous By careful design, it is possible to arrange the mass distribution together with methods of construction that will result in reducing periodic bending to a marginal figure Reducing the flexibility to a low order will enable the pilot to control the blade kinematics to requirements As a point of interest, I would mention that the calculated vertical bending of one set of rotor blades of W 9 under hovering conditions is 5 in at the tip and on a second set the bending has been reduced to less than 3 in The torsional stiffness of both sets of blades is considerably greater than in general use on most helicopters

As a possible alternative to changing the blade incidence by mechanism attached to the root end of the blade, the aileron method offers certain advantages As the outer third of the blade is the most effective it seems logical that the control should be imposed on that portion It is doubtful if change over from helicopter to autorotation can be accomplished by aileron alone and if the mean setting for helicopter operation is to be efficient then the autorotative setting will be difficult to realise This necessitates a torsion hinge for the change over so that aileron control can be restricted to within reasonable limits or just sufficient for correcting normal displacements of the aircraft The system when coupled to cyclic mechanism should be capable of carrying through the desired blade kinematics and I hope to fully investigate the possibilities at an early date The idea is not new and was proposed by quite a few of the early experimenters We also have the modern examples of Langraf, Bendix and others

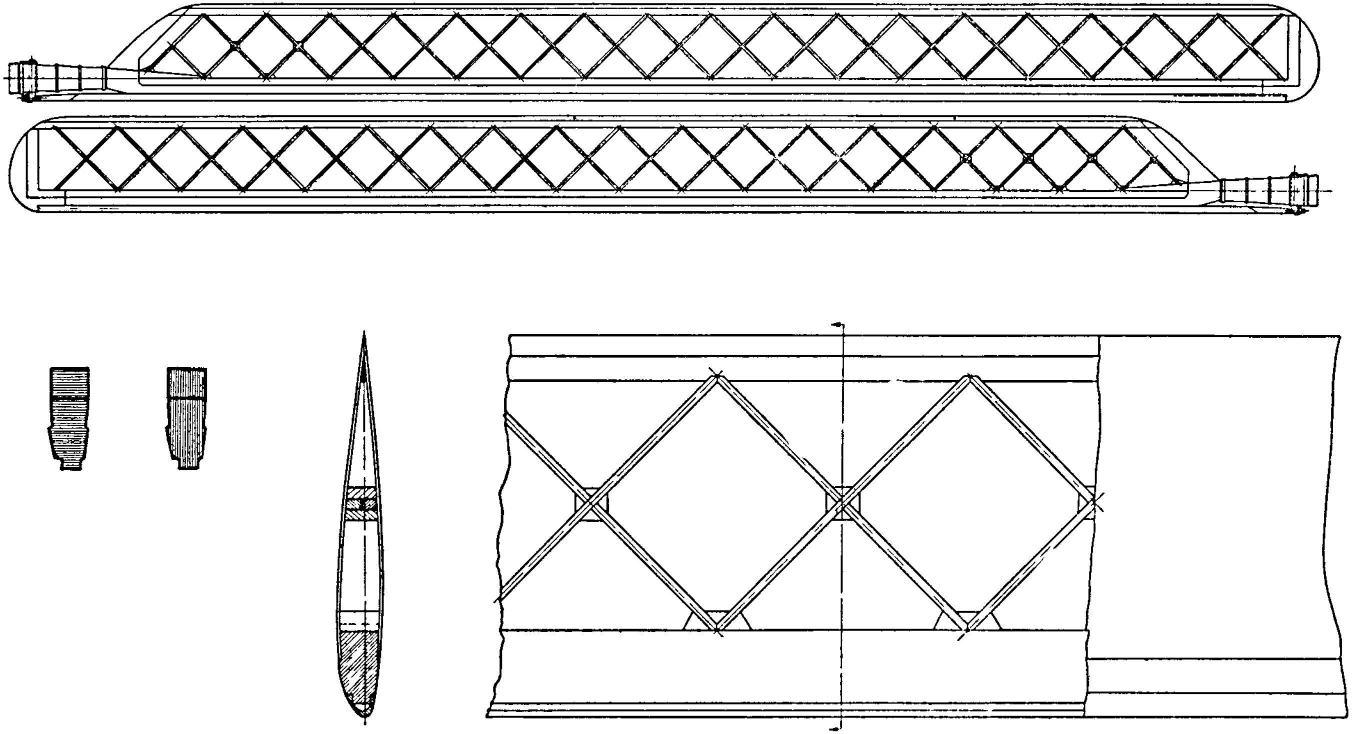
The importance of correct blade kinematics becomes predominant in translational flight at say over 60 m p h as the cyclic system of control together with the attitude of the aircraft gives the necessary pitch oscillation to suppress flapping

Inability to achieve smooth high speed flight can be attributed to a lack of appreciation of appropriate apparatus to achieve the required blade kinematics The use of modern low drag areofoils have contributed largely to the increase of lift efficiency now being attained, but torsional stiffness is very elusive when relatively low fineness ratios are employed On helicopters W 5 and W 6 the blades had a fineness ratio of 12% and the section in accordance with N A C A 23012 Great difficulty was experienced with the construction of these blades, cruciform type of rib being used to reduce the torsional and bending flexibility

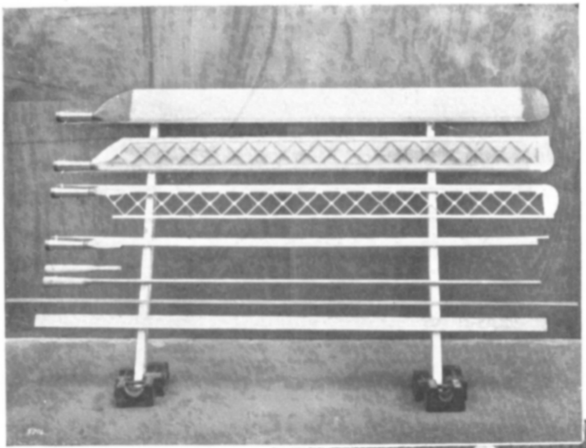
For W 9 I decided to sacrifice some aerodynamic efficiency by using a 15% fineness ratio and the resultant stiffness is considered to be satisfactory I would also mention that the stalling curve of the N A C A 23015 is not so abrupt as that of the 23012 section

In the light of past experience with Autogiros and the difficulties of obtaining blades of uniform characteristics, I decided to employ an all wooden blade construction for the Weir helicopter W 5 using moulded synthetic resin bonded plywood skins

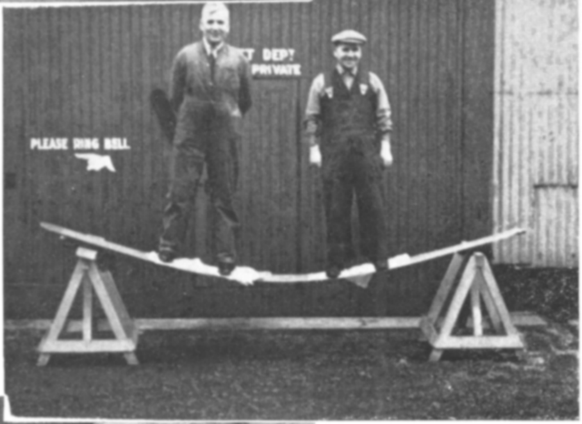
These early examples of semi-moulded blades were made by Messrs Airscrews Ltd , Weybridge, and Jablo Ltd , of London The same principle of moulded skins and compressed wood spars was used on the Weir helicopter W 6, the blades being made by Messrs Morris & Co , Glasgow, high class woodworking engineers I may say that this method of construction has given every satisfaction and was adopted in modified form for the rotor blades of the Cierva helicopter W 9 It is of interest to note that in the case of the Weir W 5 and W 6, the blades were of constant chord throughout and untwisted, whereas those of W 9 have a pronounced taper plan form and twisted out of incidence towards the tip by some 6° The estimated and measured lift efficiency of the W 9 is over 80% In the case of W 6 the transverse C G position of the blades was corrected by rolling-on to the leading edge of an extruded monel metal section the inner end being anchored to the root fitting so as to relieve the wooden portion of the blade of the centrifugal load of the metal edging The blades of the Cierva helicopter W 9, constructed by Messrs Morris & Co , of Glasgow, have the transverse C G corrected by means of lead weights built into the blade spar, whereas those made by Jablo Ltd employ embedded sintered tungston weights having a specific gravity of 16 9 The use of this heavy metal, more than twice the weight of steel, simplifies the problem of accommodation in the spar Apart from correcting the transverse C G the longitudinal location of the weights is so arranged as to reduce the vertical bending under dynamic conditions to the very small order as previously mentioned



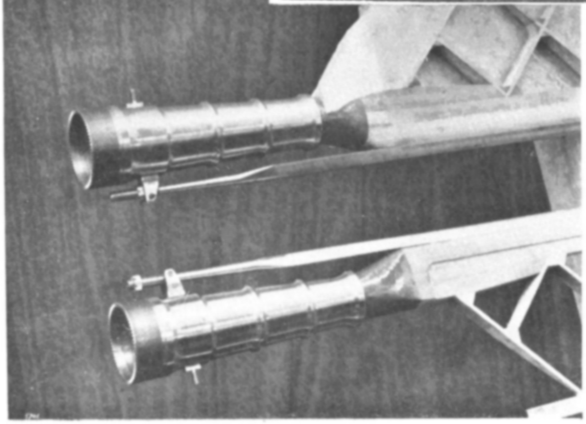
29 *Weir W 6 rotor blade construction*



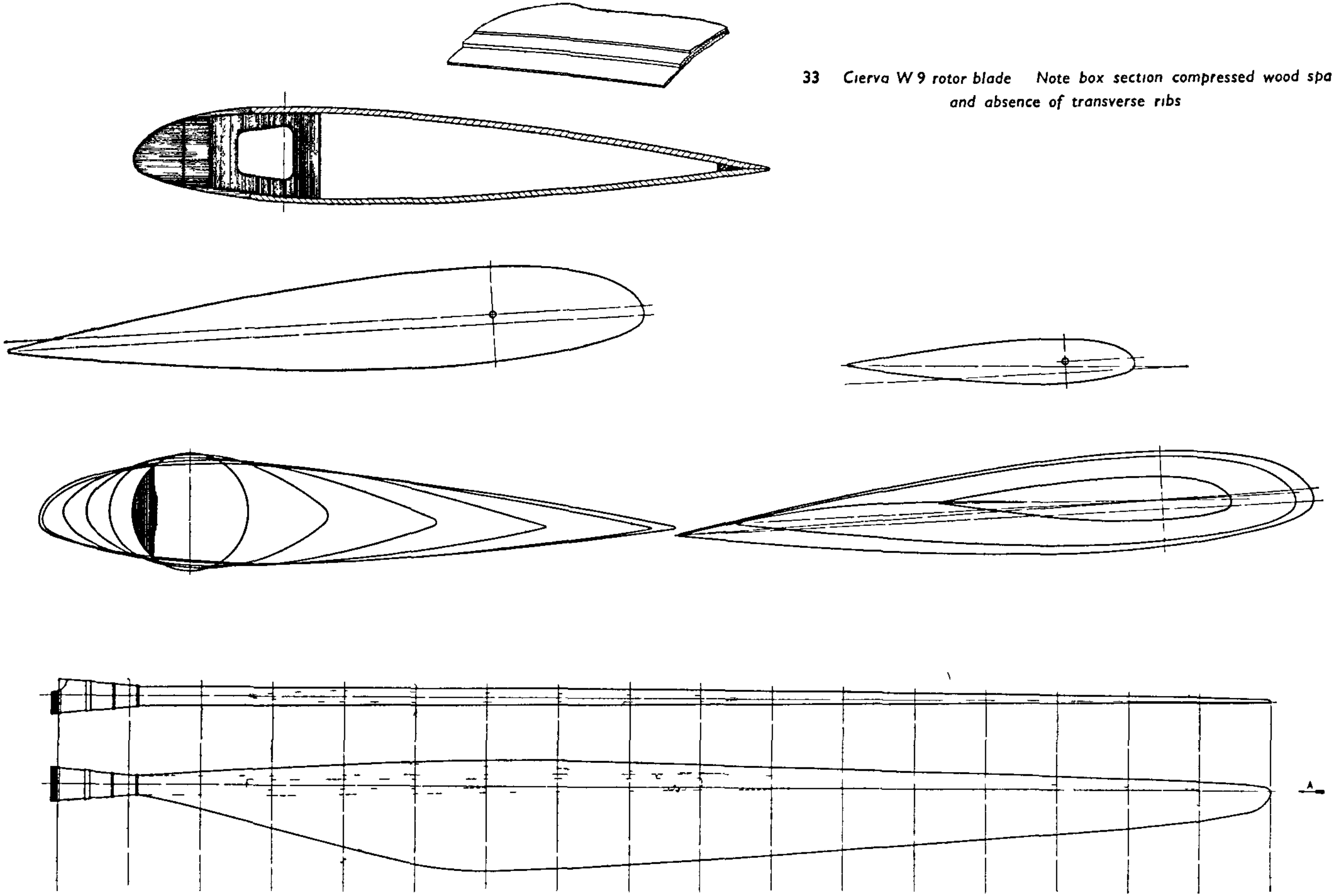
30 Weir W 6 rotor blade
Stages of construction



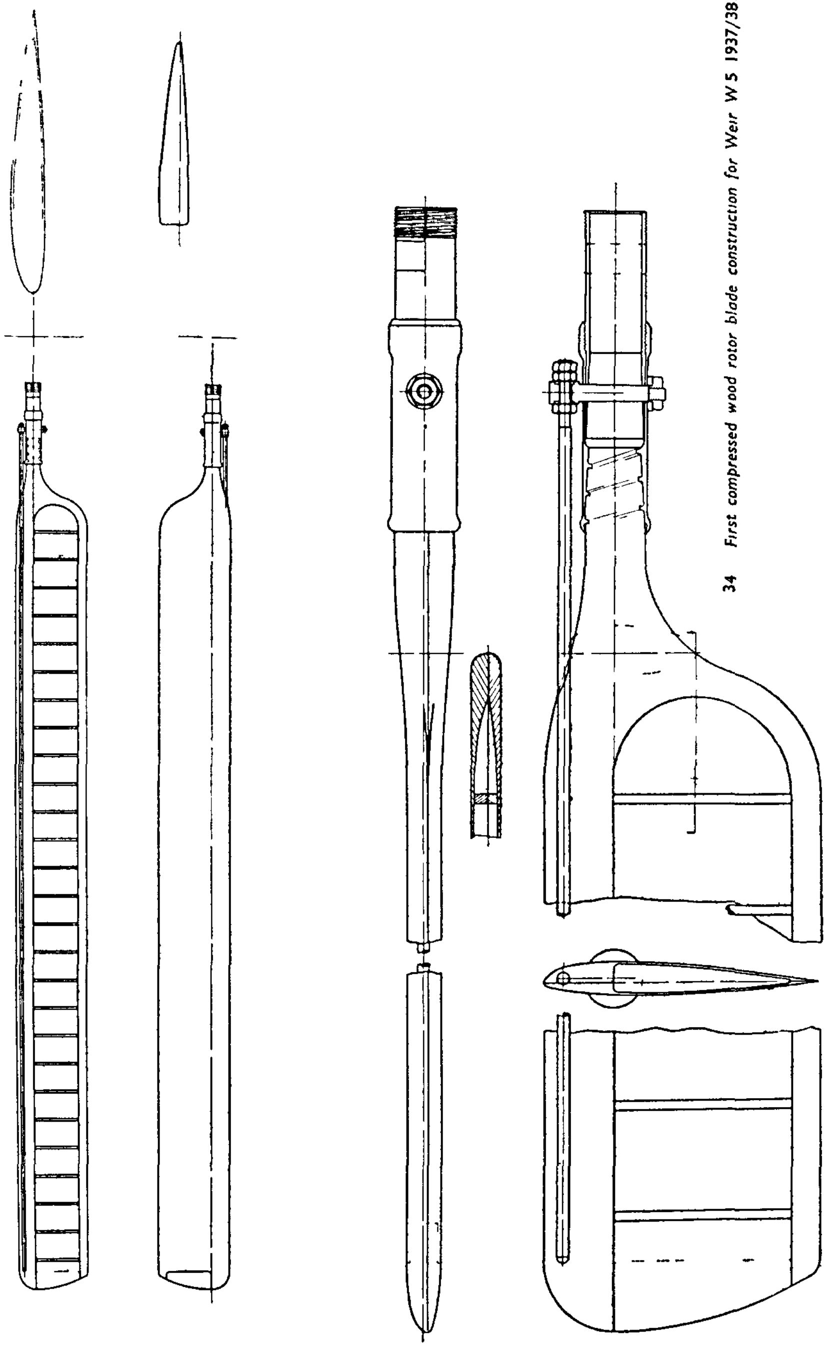
31 Weir W 6 rotor blade
supporting two men



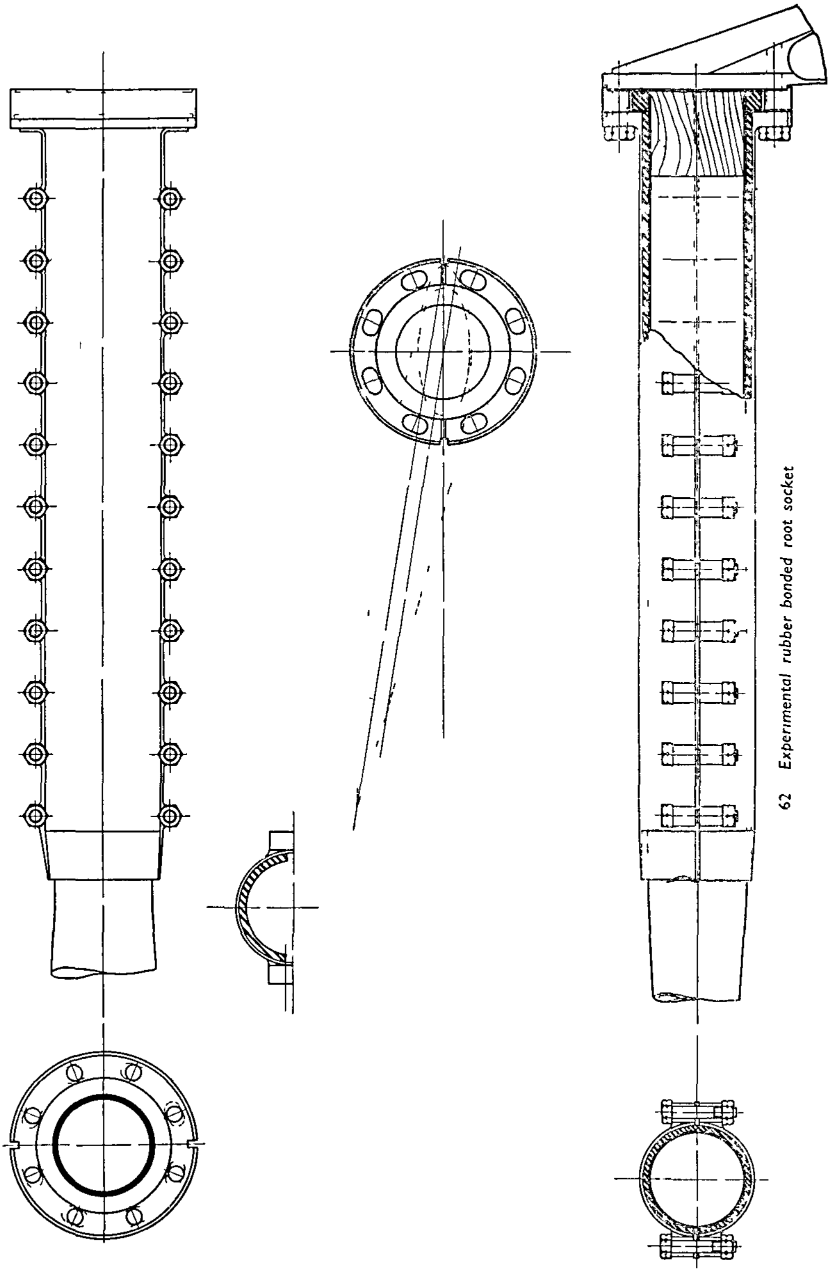
32 Root fitting of Weir W 6
rotor blade Note metal leading edge anchored to root
fitting



33 *Cierva W 9 rotor blade Note box section compressed wood spar and absence of transverse ribs*



34 *First compressed wood rotor blade construction for Weir W 5 1937/38.*

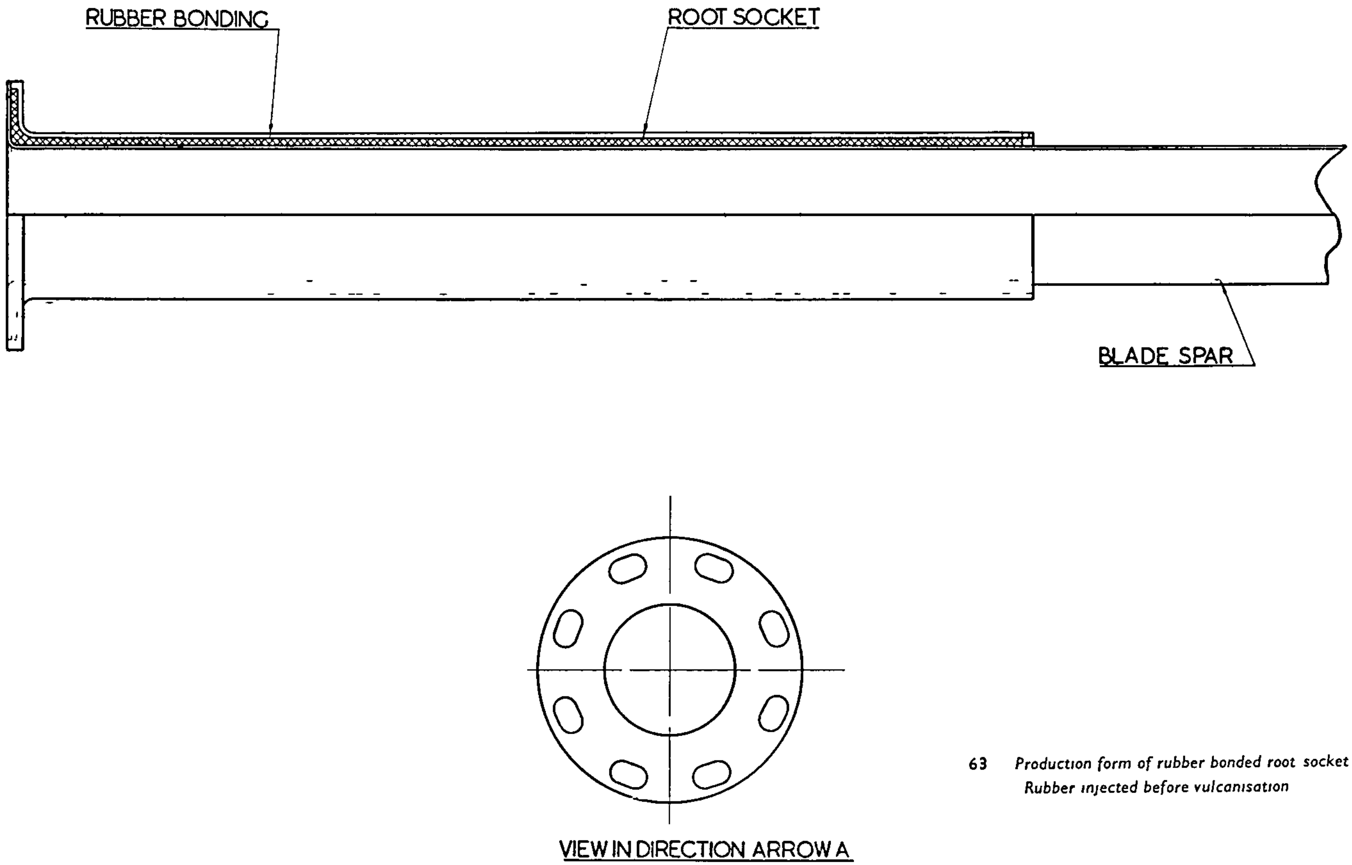


62 *Experimental rubber bonded root socket*

ONE OF THE TEST RESULTS OF THE EXPERIMENTAL FITTING

Load Tons	Deflection (Elastic) Inches	Deflection (Permanent) Inches
1	0	0
5	0×	0
10	$^{1}/_{64}$—	0
134	$^{1}/_{64}$	0
15	$^{1}/_{64}$×	0
20	$^{1}/_{32}$	0
25	$^{1}/_{32}$×	0
30	$^{3}/_{64}$	0
35	$^{3}/_{64}$—	0
40	$^{1}/_{16}$	0
Load held at 4 tons for 3 minutes	No further elastic deflection	No permanent deflection
50	$^{5}/_{64}$	0
70	$^{3}/_{32}$	0×
90	$^{9}/_{64}$	$^{1}/_{64}$
95	Tube started to fail in bearing	

NOTE Tube was held by one No 10 morse taper pin which in this instance had been very badly fitted causing excessive local bearing pressure on tube



63 *Production form of rubber bonded root socket*
Rubber injected before vulcanisation

The root fitting of the rotor blade has always been a problem in itself When using a steel tubular spar I have found the best method to employ is that of rubber bonding the root end socket to the tube Strangely enough the experimental fitting is still in existence as it has defied all attempts to pull the tube from its socket, mainly because no other form of root end attachment can be found with equal resistance to that of the rubber bonded end Although this form of attachment is not in use at the present juncture, there is reason to believe that its unique properties will be fully appreciated in due course

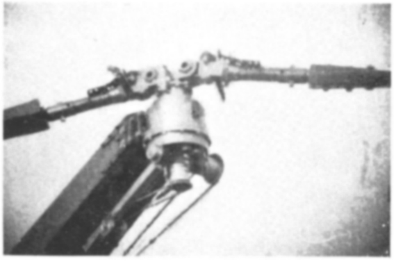
The form of root fitting that was used on the Weir W 6 was again employed on the Cierva W 9 A set of blades has also been tested with screwed-on root fittings similar to those of wooden airscrew blades Both types appear to be satisfactory

On the question of rotor blade finish doping and polishing fails to withstand the effects of rain, hail, etc , so I arranged for one set of blades of the Cierva W 9 to be finished with Plastoglaze This material is sprayed on and cured by means of hot carbon dioxide gas produced in a special generator The curing process takes about 10-15 minutes for each coat, the blade being subsequently rubbed down and polished Five or six coats at least are advised I would also mention that static and dynamic balancing is corrected during spraying and polishing The resultant finish is almost glass hard, impervious to water, oil, petrol, etc , and retains sufficient flexibility to prevent cracking of the coating under deflection

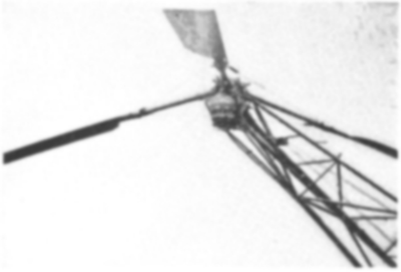
The all metal blade occupied my attention for many years and although it should be possible to evolve a design meeting with the general requirements, I must say my experiments have not been very successful The total weight is, of course, one difficulty, it being inadvisable to have the ultimate rotor coning angle too small Perhaps new materials and improved methods of fabrication will become available in the near future that will solve some of the associated problems but the present composite wooden blade is also undergoing further development

Rotor Controls

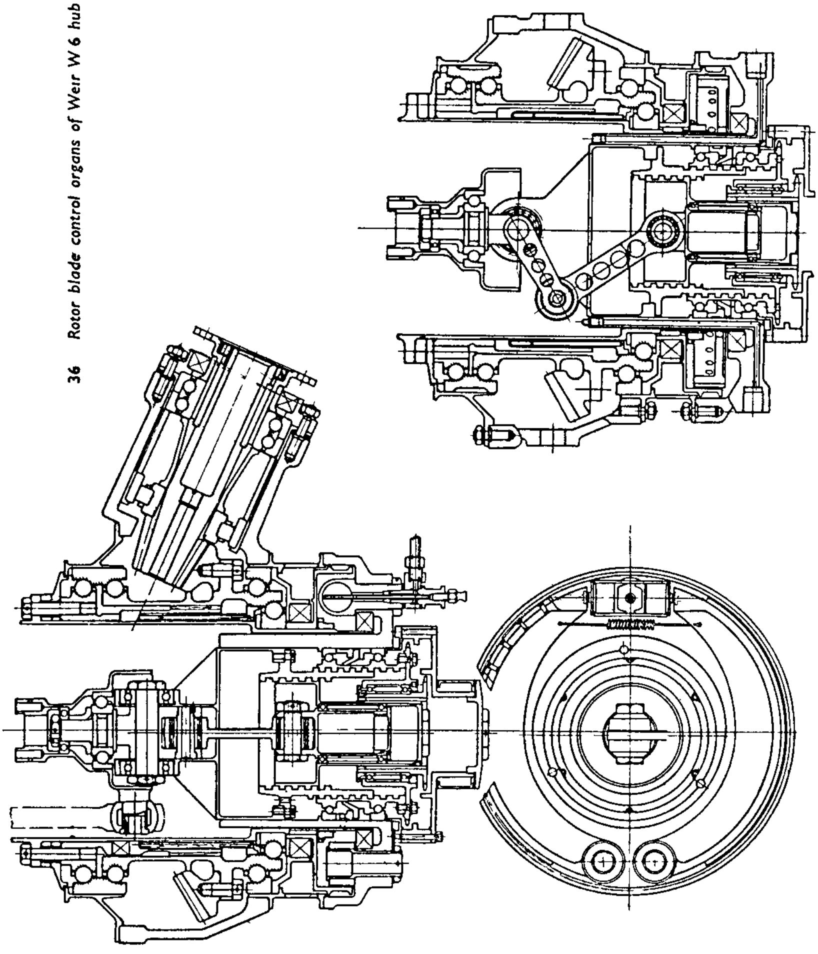
One of the problems associated with rotating wing aircraft has been the moments in the pilot's control arising from the blade kinematics Early attempts at irreversible controls on the Autogiros were unsuccessful but the screw jack system employed on the Weir helicopters W 5 and W 6 presented no difficulties as regards pilotage



35 *Weir W 5 rotor hub mounted on machine Observe the screw jack control to internal swash plate*



37 *Weir W 6 rotor hub and blades mounted on outrigger Note blade interbracing cables*



36 *Rotor blade control organs of Weir W 6 hub*

Here then is an example of what is termed the " impersonal control " which, of course, is similar to that of the German Focke machines, and I believe, the Sikorsky R 5 It would have been quite an easy matter to arrange some spring resistance or " feel " to the control column but was found to be unnecessary This was further confirmed on the Cierva helicopter W 9, which employs hydraulic servo controls super-imposed on the mechanical control, the control column being irreversible as from rotor to control column On the other hand, the control effort is of a very low order and quite smooth in action, so that this system is likely to find favour on helicopters, more especially the larger machines The centrifugal pitching or torsional moments of the Autogiro rotor blades are relatively small as the angle of incidence is correspondingly small, but in the case of the helicopter blades working at substantially three times the pitch setting of the Autogiro blades the moments can be considerable The loads arising from the centrifugal pitching moments are, of course, domestic to the rotor hub and blade articulation when cyclic pitch is in say the neutral position so that all the blades have the same pitch setting Application of cyclic pitch gives the differential effect from which the moments arise These remarks, with some qualification, also apply to the orientable rotor hub The friction valve of the screw jack control when unassisted by servo mechanism has many limitations, especially on large multi rotor helicopters

Stability and Control

Under this heading we have perhaps the outstanding problems of the helicopter There seems to be a general impression that once the fixed wing had been replaced by the lifting rotor, any person of reasonable intelligence could enter the pilot's seat and take the air in safety and in comfort Although I had some relevant misgivings when constructing the Weir helicopter W 5 in 1937 I did not anticipate the utter disappointment I experienced when trying to hover the Weir W 5 in the early part of 1938 I was most perplexed by the rapid rate of displacement of the machine about all axis and the pilot's control lay-out was completely inadequate A careful investigation of the associated parameters indicated a hair trigger control system but owing to the small size of the aircraft it was thought that even then the normal pilot's reactions would be too slow to meet with the requirements It was also apparent that the machine possessed no static stability whilst hovering and very little dynamic stability There appeared to be no solution to the problem of static stability but the dynamic stability could be improved by increasing the moment of inertia about the pitching axis by introducing some horizontal offset of the flapping hinges together with an additional five feet added to the tail end of the fuselage At the same time, the angle of the side outriggers carrying the rotors was changed from 11 5° to 22° A normal control column and rudder bar replaced the rocking wheel control The result was most satisfactory and hovering on short ropes in the erecting shed became possible although the ground interference was most marked Shortly after this the Weir W 5 made its first free flight under full control The data arising out of these tests was successfully employed for the Weir W 6 that was flown on the first day it was taken to the test field Control of the aircraft, however required much skill and practice except under conditions of translational flight when the tail plane, positioned in undisturbed air, would provide some reasonable static stability on the phugoid path, the latter being of " easy " configuration on account of the small amount of inertia of the aircraft as a whole

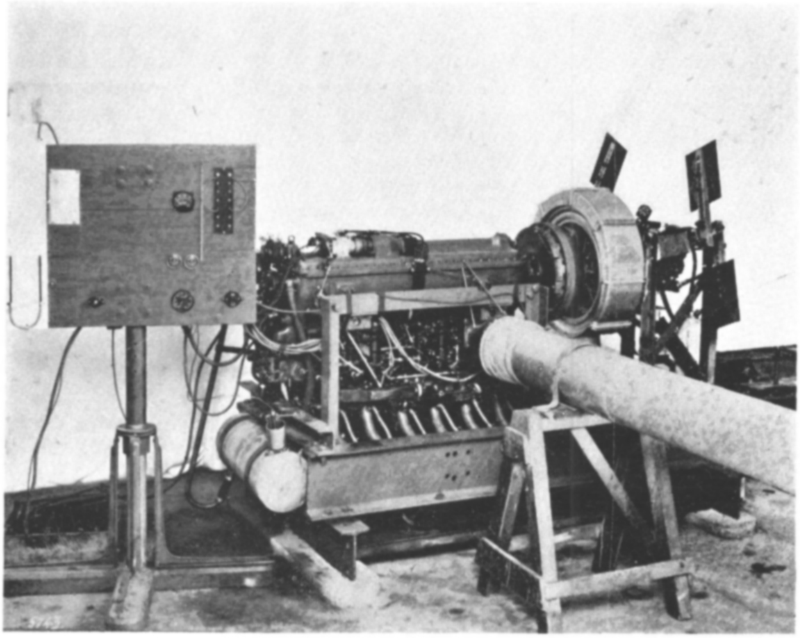
If the helicopter possessed inherent static and dynamic stability the question of control would be relatively simple and mainly that of direction Unfortunately, we find our control system becomes a slave to the shortcomings of this attractive aerial vehicle With my single rotor machine, some dynamic stability has been introduced by the horizontal offset of the flapping hinges which permits, when hovering, even in light winds to remove the hand from the control column for some ten to twenty seconds Slight static stability on the phugoid path is also present In spite of this, it appears that the aircraft must be constrained in equilibrium which calls for a very sensitive and quick acting control, also a pilot having the necessary skill and training The pilot thus becomes the datum of " controlled stability " but this can be relieved to some extent by the horizontal offset of the flapping hinges or its equivalent in the form of some partially independent datum, as given by the Bell inertia bar constraint The Bell system is at present limited to the use of two bladed rotor systems with the attendant problems of vibration Perhaps the ultimate solution to the stability of the single rotor helicopter using more than two blades will be a reasonable horizontal offset of flapping hinges together with an adequate system of instrumented automatic control

With multi-rotor helicopters such as the side-by-side, we find in the Langraf machine an arrangement that can give quite good static stability in forward flight This is achieved by using unarticulated rotor blades together with cyclic pitch control and arranging the C G of the aircraft to be in front of the centroid of lift With the Focke, Weir and Platt Le Plage machines using articulated rotor blades it becomes necessary to employ a tail plane to give a similar effect With the tandem configuration, such as the American Piasecki or P V it is possible to adjust the centroid of lift so that the aircraft can be trimmed to provide some static stability in forward flight although the rotor interference introduces many secondary problems There is very little to choose between articulated and non-articulated blades with this particular configuration The Cierva ' Air Horse,' three rotor helicopter, appears to give the optimum arrangement and can be shown to possess sufficient dynamic stability about the pitching and rolling axes whilst hovering together with adequate static stability when in forward flight Here again it is possible to use articulated rotor blades Rotor interference is estimated to be appreciably less than that of the tandem arrangement

To conclude this section, I am of the opinion that having reached the state of full appreciation of the difficulties of stability and control, the solution although not simple, will be reached in the near future The practical application will of necessity, differ according to the type of helicopter chosen

Power Units

The internal combustion piston engine is a good servant but makes a bad master My considerable experience in the design and application of piston engines to road vehicles of all types, stationary power plant and aircraft, suggests that though this form of prime mover has great versatility, nevertheless, every application needs individual study Some years ago I designed a small two cylinder



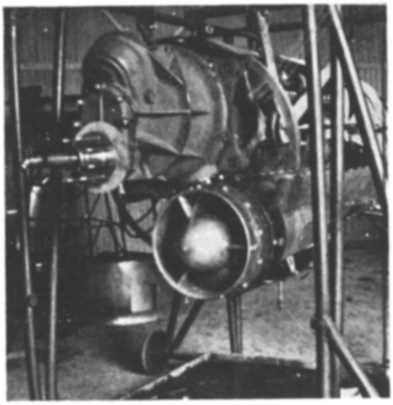
Power unit of Weir W 6 complete with fluid flywheel cooling fan and power distribution box with fan brakes The large tube is attached to the carburettor air intake

opposed engine for use on the early light aeroplanes which gave quite reasonable service until it was decided to introduce a reduction gear between the airscrew and crankshaft Amplification of the torque peaks through the gears either resulted in broken crankshafts, damaged gears or fretting of the splined shafts The power output was also lower than calculated In spite of past experience, I was asked to design a two cylinder geared engine as late as 1933 To keep the aircraft flying it was necessary to introduce a special device to damp out the torque peaks associated with this type of engine The additional weight and cost of this damping component ruled out the installation as uneconomical For the first Weir helicopter W 5, I used, purely on the score of economy the small four cylinder in-line air cooled engine that I designed in 1935-36 for the light single seater Autogiros Fortunately, the crankshaft was exceptionally robust and managed to stand the racket for the relatively short life of the experimental aircraft The overall gear ratio between engine and rotors was 8 4 to 1 so that trouble with torsional vibrations was to be expected No doubt the long transmission shafts damping effect in the numerous bearings and the elastic constraint of the rotor blades in relation to the rotor hubs, played an important part as no trouble was experienced

For the Weir helicopter W 6, employing a Gipsy Six engine, with its relatively long crankshaft, the difficulty was met by the fitting of a Fottinger coupling fluid flywheel

In practice this was found to give very good results and also provided a most satisfactory hydraulic rotor starting clutch in the following manner The low speed drag of the coupling was resisted by a transmission brake which when released, would allow the engine to progressively start the rotor Increase of engine speed would bring the coupling into full operation with a final slip of some 3% On the research machine Cierva W 9, the fluid flywheel was not included and evidence of the amplification of the torque peaks is present in the form of fretting of the centralising cones holding the clutch component on to the crankshaft, also on the teeth of the secondary reduction gear pinions This does not only apply to the Cierva W 9, but it is found on other helicopters now in use I anticipate an improvement with the Rolls Merlin engine proposed for the large Cierva three rotor helicopters now under construction, mainly on account of the large number of cylinders and the short stiff crankshaft I am not prepared at this juncture, to suggest a formula of the application of the Internal Combustion Piston Engine to the helicopter, but it is just possible that by taking into account all the relevant parameters, it might eventually be deduced to simple terms, an important factor being the piston head area A full explanation is somewhat involved, but I have a case in mind where a low speed engine was replaced by a high speed engine having a 25% increase power output In spite of careful adjustment of the associated components and the rotor system the performance of the aircraft was not improved or we might say that the additional power of the high speed engine was not doing the additional work on the air What I have just outlined indicates the difficulties of finding a suitable power unit for the light two seater helicopter that will have a low purchase figure together with reliable operation and small maintenance

Whilst on the question of piston engines my practical experience leads me to favour the liquid cooled engine together with a liquid cooled exhaust manifold as being the most economic solution to the problem of the submerged engine as is generally the case with the helicopter Fan cooling of the Gipsy Six in the Weir W 6 absorbed some 8% of the maximum power The installation of the same engine in the Cierva W 9 is so arranged that adequate cooling is achieved for approximately 3 25% of the maximum power, but in this case it represents part of the thermo dynamic cycle employed for rotor torque balance system



39 *Cierva W 9 power unit on assembly stand*
Note engine cooling boost fan

Liquid cooling of the Rolls Merlin for the Cierva Air Horse is calculated at less than 2½% The modern high efficiency axial flow fan and heat exchanger permits the heat to be extracted in the most scientific manner A large percentage of the weight of the cooling installation is cancelled by the reactive thrust of the cooling fan

Air cooling of the exhaust manifold of the submerged engine presents a difficult problem more especially as the rotor slip stream velocity is insufficient for the purpose To avoid local hot spots is very wasteful as regards fan horse power and such hot spots represent a potential fire hazard if drops of oil are present or airborne to the localities Instances of this have already been observed The obvious solution is to liquid cool the exhaust manifold and a full scale engine has already successfully passed some comprehensive tests The heat to be removed to reduce the temperature to a reasonable degree and to avoid evaporation is slightly more than that dissipated by the engine cylinders A safe and readily controllable means of cabin heating by hot liquid also becomes available Silencing of the engine exhaust of helicopters must also receive attention The noise level of the lifting rotor is exceptionally low as compared with the airscrew of the normal fixed wing aircraft, the outstanding noise being that of the engine exhaust The energy in the exhaust gasses is mainly in the form of heat so that by liquid cooling the manifold the major part of the silencing will have been carried out Further, the ultimate temperature of the gas leaving the manifold will permit the use of aluminium alloy for the final exhaust silencer

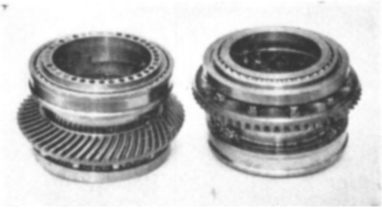
Burning out, distortion and cracking of present day exhaust manifolds is a constant source of worry Special non-oxidising alloys must be used which are costly and require considerable skill in fabrication

I cannot leave this subject without referring to the gas turbine The type I have in mind is that in which power is taken from the turbine shaft Patents for which I applied in 1943 indicate a practical design study covering the use of the geared turbine The high velocity turbine exhaust, in conjunction an augmentor fan is used for torque balance in a somewhat similar manner to that employed in the Cierva helicopter W 9 Investigations have also been made into the use of single and twin turbine installation for the Cierva large three rotor Air Horse, and when such units are available it appears that taking everything into account and in spite of the increased fuel consumption over that of the piston engine, the advantage is in favour of the turbine installation up to some 2½ to 3 hours cruising A direct analogy to this, of course, is comparison between the present petrol engine and the Diesel cycle or in other words, the effect of compression ratio

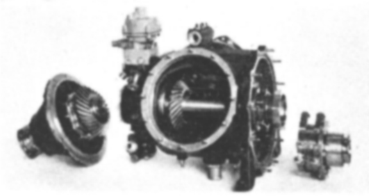
TRANSMISSION

I find it impossible to deal but briefly with transmission on account of the time at my disposal It will, however, be appreciated that 14 years' experience in this connection has resulted in a background of knowledge, which at this juncture is of the utmost value Long transmission shafts present no difficulty if carefully designed and applied No failure on this account was recorded with the relatively crude arrangement on the Weir helicopters W 5 and W 6 With the single rotor machine such as W 9, the solution is, of course, quite simple Improved methods for production of long, straight, large diameter tubes would be welcomed

I should perhaps mention the torque metre used on the Cierva W 9 in 1944-45 which is no doubt the first time that such a device has been used on the helicopter The torque was measured by the very small torsional deflection of the main rotor shaft and amplified through two sets



40 *Weir W 6 rotor hub gears and ratchet free wheels to give correct phasing of rotors*



41 *Weir W 6 torque distribution box Of special interest is the constant speed unit mounted on the left hand top side and the torque breakdown device at opposite end*

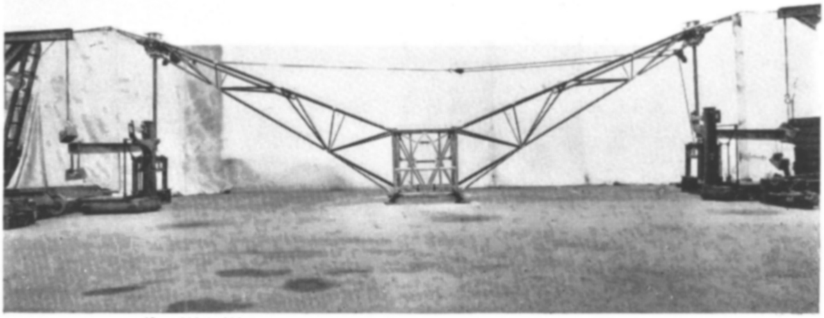
of planetary gear train, the deflection being magnified ten times so as to give a direct reading in a calibrated dial in the pilot s cockpit This apparatus provided the means to check the power applied to the rotor and tail jet, also permitted a close check of the rotor efficiency

Undercarriages

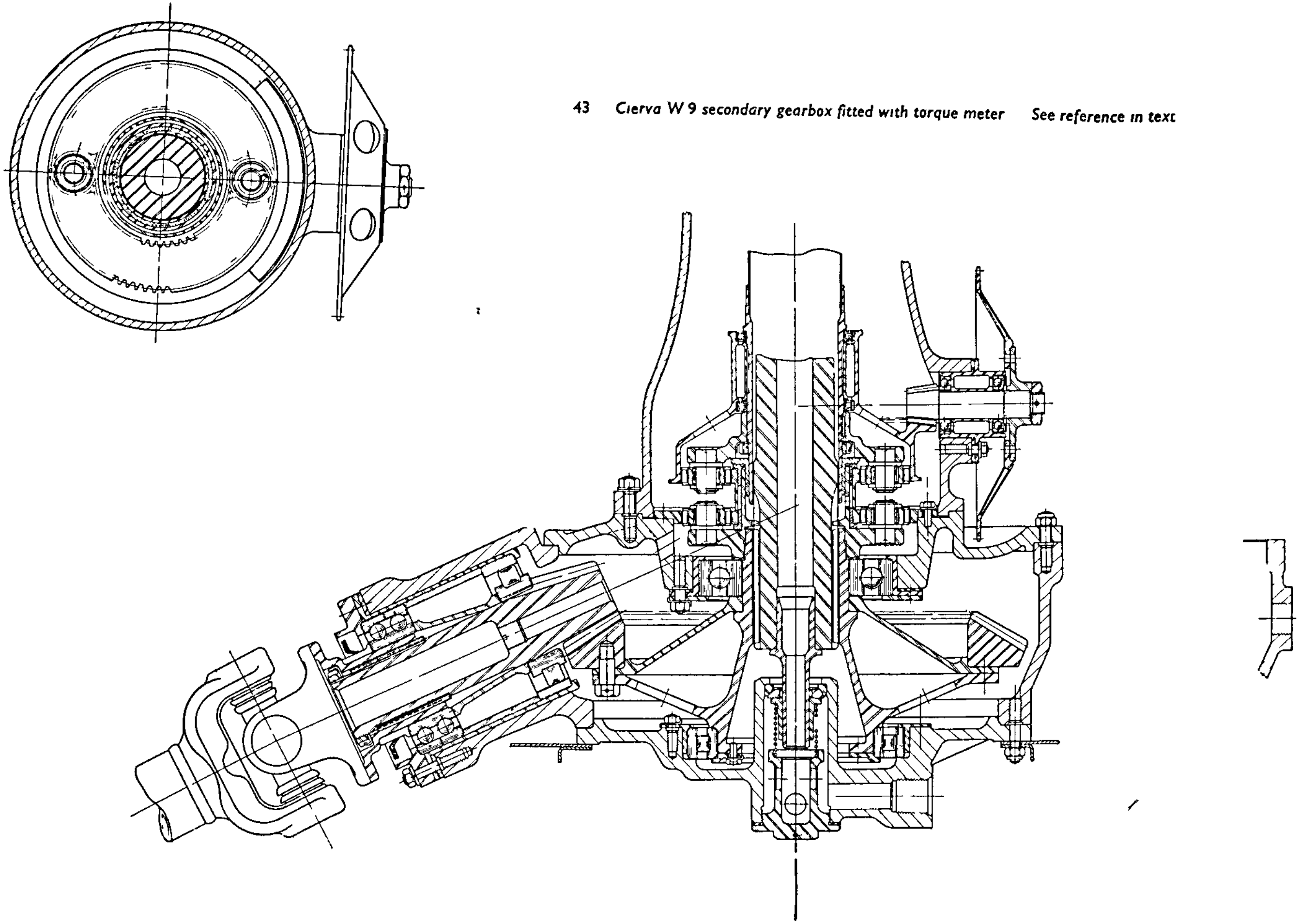
Practical operation of Autogiros and helicopters with which I have been associated bring into prominence the rather serious hazard of mechanical failure when hovering or slow flying up to 200 feet above the ground In 1939 I provisionally protected the use of the kinetic energy stored in the rotor to cushion out the landing when a few feet from the ground Unfortunately, this provisional patent was allowed to lapse The principle however, is in use today and is perhaps the saving grace of the present helicopter in case of emergency To use this effect to advantage, it has been found possible to design apparatus that is automatic in effect to give the optimum rate of descent either as a helicopter or when under autorotation Pure vertical landing can be accommodated by a long travel undercarriage, which in the case of the large Cierva ' Air Horse ' is 5 feet The travel, of course, depends mainly on the disc loading of the particular machine For the single rotor type of machine this is met in a somewhat similar manner by the employment of a special form of duplex undercarriage giving the same long travel effect but having the appearance of a normal configuration

MECHANICAL DETAILS

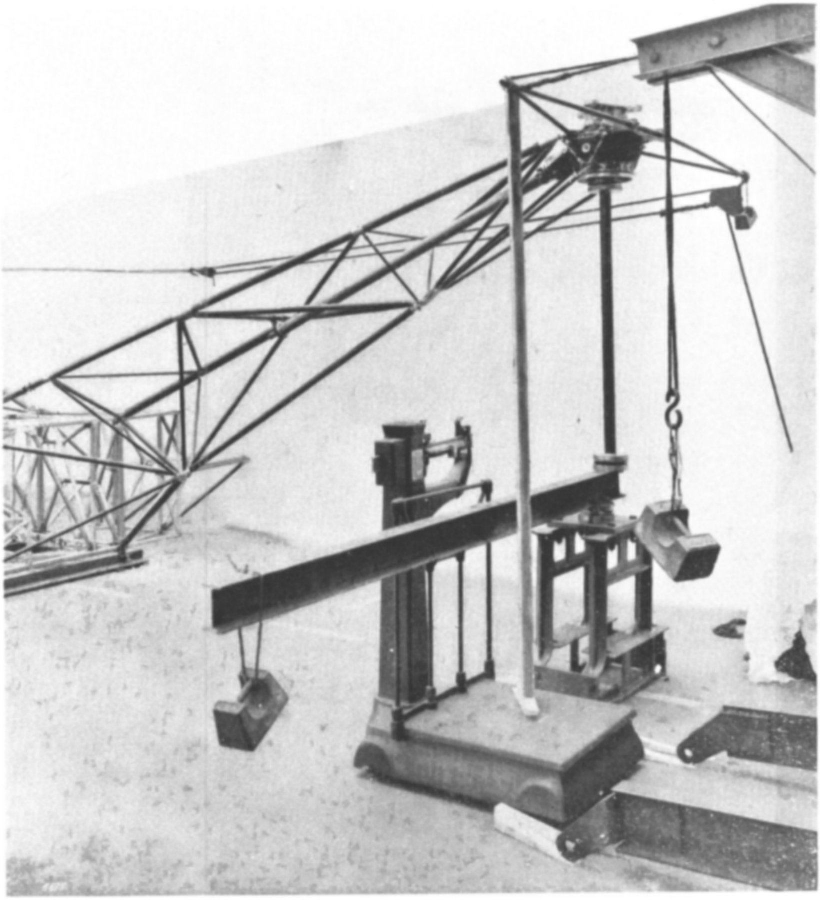
If time permits I hope to show on the screen a few mechanical



42 *Weir W 6 centre section and outriggers undergoing proof load tests*



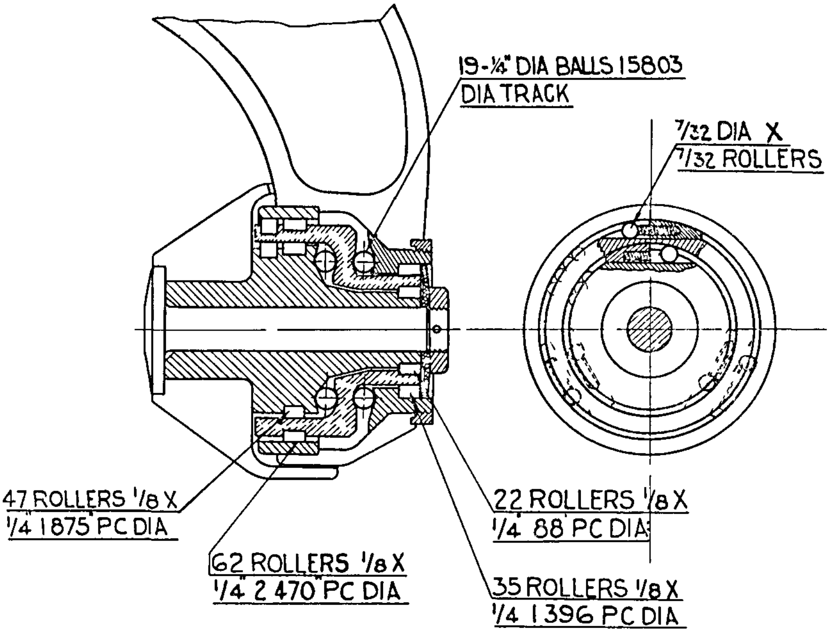
43 *Cierva W 9 secondary gearbox fitted with torque meter* *See reference in text*



44 *Close up view of loading device employed for proof test of Weir W 6 centre section and outriggers*

details which may be of interest to the audience and gives some idea of the intensive research that has taken place in the past years

One very important component of the rotor system employing cyclic pitch control, also the orientable hub with Delta III blade coupling, is the torsion bearing of the rotor blade In the case of the Autogiro angled hinge system, reasonable control effort was only possible when the plain bearings had been replaced by ball or roller bearings Unfortunately, the small order of pitch oscillation during flight, some ± $1\frac{1}{2}$ degrees, caused the balls to Brinell the race tracks, thus increasing the frictional moment of the bearing and introducing considerable roughness in the system Roller bearings were also found to be unsatisfactory on many counts To keep the overall friction down to the minimum it was necessary to secure correct geometrical rolling of the balls and this was accomplished by the use of specially formed V



64 *Inching bearing pack for thrust loads under small torsional oscillations*

grooved tracks By arranging a pair of the V grooved races in tandem and by the application of the roller free wheel principle, the oscilations would cause the pair of races to " inch " round under load and so eliminate the indentation of the race tracks Many hundreds of hours of full load testing proved the bearing to be highly satisfactory It was completely reliable and would respond to small oscilations of ± 20 minutes The frictional moment was approximately half of that of a new and normal ball thrust race, the friction actually becoming less after the first 50 hours before levelling off to remain constant over some 500 hours A drawing of this bearing is included which gives details of the design There is no doubt that the bearing pack could be used to advantage on the helicopter in spite of the pitch oscilation being of a much larger order The very low frictional moment would be most helpful, especially on the large machine

Odd Types

I should have liked to have given my experience in the theoretical investigation and practical design of such types as the Gyrodyne, the reactive propulsion rotor of helicopter W 8, and the rocket assisted Autogiro/helicopter now being developed by the Autogiro Company of America, but this I am afraid must be left to a later date

Conclusion

In conclusion the helicopter is with us in many practical forms, but of course, utilising the same basic principle It should be deprecated that we are at present saddled with considerable complexity but this appears to be the case in the development of most simple machines in the search for efficiency and to bring them within practical scope I can instance many examples, including the simple 3 port 2 stroke engine, the thermodynamic duct or ram jet which we now see in the form of the gas turbine and sometimes for jet propulsion The trend in design is towards further complexity but thanks to the excellent work of the A I D we should have no fears in this connection, confirmation of which is given by the mass production of the most delicate apparatus, aircraft engines and components not only in this country but throughthe world As long as the A I D are with us, or alternatively, the Civil version the A R B we can look forward in confidence to the successful and safe operation of helicopter aircraft

As regards operational costs, I find that the large three rotor helicopter can carry freight at a lower cost than that of the equivalent fixed wing aircraft, this of course, taking everything into account including maintenance, airfields etc , but at a reduced speed In other words, we must pay for speed, although for short distances even the speed can be in favour of the helicopter

It will be noted that I have not confined my attention to one configuration of helicopter At the present state of the ' art ' constructional and other limitations impose restrictions on rotor diameters, so for useful loads of over 1,000 lbs we should employ multi-rotors Careful calculations indicate an overall gain in efficiency by keeping the rotor diameter within reasonable limits At present I have design studies in hand covering light two place single rotor helicopters, 2 up to 5 place single rotor machines with reactive thrust torque balance, three rotor passenger and freight helicopters up to payloads of 3 to 4 tons and even larger four rotor types to lift 8 to 9 tons Even the tandem configuration and improved Gyrodyne has not been forgotten Once the complete rotor circulation under all regimes of flight is properly understood, the pieces of the jigsaw puzzle begin to fall nicely into place Perhaps the best visual experience I had as regards circulation, was during the recent crop spraying tests by Messrs Pest Control Ltd , on a helicopter suitably equipped by the Cierva Autogiro Co , Ltd I shall one day endeavour to obtain a photographic record of this rather puzzling phenomenon

Finally, the time factor is not on the side of those engaged in the art and everything possible should be done to get practical helicopters into service without delay No one can say at this juncture, how long it will be before we shall have control of the release of atomic energy and if and when this is secured the whole aspect of aerial flight and aerial machines may be subjected to a drastic change

I trust that the ambitious student will find some pointers in this paper that may help to unravel some of the problems of design and eliminate disappointment

Mr Chairman, Ladies & Gentlemen,

I thank you for your attention

Mr H A Marsh—Chairman
Ladies & Gentlemen,

I feel sure you have thoroughly enjoyed Mr Pullin's very interesting lecture and I call upon Mr Norman Hill to propose a vote of thanks I would remind you that some time has been allowed for discussion Mr Pullin will be very pleased to answer any questions

DISCUSSION

Mr O L L Fitzwilliams (Member)

Enquired as to the location of the freewheel component in the Cierva W 9 which he understood was in the rotor hub This was confirmed by Mr Pullin and the reasons given as to the choice of location Its relationship to the rate of vertical descent is now included in the text

Mr R G Robertson (Member)

Was it not a fact that some years ago experiments were carried out with the use of aerofoil surfaces fore and aft on the fuselage in the vertical plane for torque correction?

Mr Pullin agreed that such tests had been conducted (see text) but as he aimed at a stable fuselage the aerodynamic surfaces were confined to that portion of the fuselage behind the rotor pylon In any case, the symmetrical arrangement would suffer in the same manner as the non-symmetrical model

Major H O Nelson (Member)

Have any experiments been carried out with variable sections on a rotor blade?

Mr Pullin assumed that Major Nelson referred to a variation of the section as from root to tip Comprehensive tests were conducted on the Autogiro but the results were only marginal and did not warrant the constructional difficulties On the other hand, the moulded blades on the Cierva had the adequate variation

Dr Hislop

Should the constant speed unit be applied to the engine throttle or to the rotor pitch control?

Mr Pullin gave his views and thought that in the hands of a skilled pilot the constant speed unit should be applied to the engine throttle This unfortunately placed the onus of change over from helicopter to autorotation on the pilot As applied to the rotor, precision flying close to the ground was impaired owing to the limitation of engine power and the moment of inertia of the rotor He was experimenting with a combination of the two systems including an automatic change over

Group Captain Howard

Raised the question of the danger period when hovering between 30 and 300 feet He thought that an increase in the weight of the rotor blades would make more kinetic energy available for emergency landings

Mr Pullin agreed that this could be done but the possible increase of blade weight would not give sufficient kinetic energy to meet the case The long travel undercarriage appeared to be the best solution at this juncture

Mr O Vines (Member)

Does the plastic material referred to for rotor blade finish adhere to wood and metal?

Mr Pullin Provided the wood or metal is virgin material, i e not having been previously painted or treated, the plastic will adhere in a satisfactory manner

A Visitor

Asked for an explanation as to the inclusion of a constant velocity joint in the Cierva W 9

Mr Pullin explained the Hooke's joint effect and how it was associated with the rotor hubs of helicopters

Mr L S Wijdortchich (Member)

Enquired as to the time lag of the reactive thrust yawing control

Mr Pullin explained that the time lag on the Cierva W 9 was approximately 75 second but did not affect the hovering flight to any appreciable extent W 9 was a pure research machine but the resultant design study had reduced this lag to under 3 second

Dr Hislop

Was anything being done to improve the longitudinal stability of single rotor helicopters?

Mr Pullin stated that the Cierva W 9 had been designed with quite a large horizontal offset of flapping hinges for this purpose A full report will be issued in due course

Mr F H Dixon (Member)

Had experiments been carried out with deflecting the tail jet for torque control while maintaining constant reaction

Mr Pullin pointed out that the Cierva W 9 is fitted with tail jet deflectors which can effect the trim about the pitching and rolling axes at the same time as giving torque balance The direct control of fuselage attitude about the pitching axis was most useful as regards C G shift

Mr Garraway (Member)

Owing to scale effect, was the data obtained from models reliable?

Mr Pullin replied that quantative data except for direct comparison with other models of similar scale should not be regarded as of practical use On the other hand, qualative information was most valuable and instructive It could save time and money when related to full scale tests

Mr F H Dixon

Written question

Dear Mr Pullin

In thanking you for the most interesting lecture which you gave us last week, there is one question which I should like to have put to you before the meeting closed Possibly you may be able to answer it in the report of the lecture —Would it be opportune to give us some figures for duration, height and distance, established by the W 5 and W 6 during the flight trials? In view of the historical importance of the work done by yourself I feel that these data would be of great interest to all of us

Yours sincerely,

Signed F H Dixon

Mr Pullin

In response to Mr F H Dixon's letter I have included a brief history sheet of the flying of the Weir helicopters, W 5 and W 6

MAKING HISTORY

G & J Weir, Ltd
Cathcart,
GLASGOW Licencees of the
Cierva Autogiro Co Ltd
Co Ltd

HELICOPTER W 5

Designed and constructed by Messrs G & J Weir, Ltd

Chief Designer—Mr C G Pullin
Test Pilot—Mr R A Pullin

Brief Specification

Single seater fuselage carrying outriggers on either of the fuselage supporting two bladed rotor hubs Cyclic and collective pitch control Rotor diameters 24 feet running at 435 r p m Powered by Weir 50 h p 4 cylinder in-line aircooled engine (blower cooled)

All-up weight 860 lbs

Design commenced in October 1937 and first free flight at Dalrymple June 6th 1938

This was Great Britain's first successful helicopter and apart from the German Focke machine, flying at the same time, was the world's second successful helicopter It was and still remains the smallest and lowest powered helicopter to give flight demonstrations to officials of the M A P etc

Over one hundred power take-offs and landings were made and the pilot's licence endorsed for helicopter flight Maximum speed as checked at Dalrymple was 70 m p h

Rate of climb not measured but estimated to be 400 ft /sec at 30 m p h

The machine could fly forwards, backwards, sideways and rotate about the yawing axis

This aircraft was in use most of the time between June 1938 and July 1939

The flying of this helicopter was of necessity confined to the precincts of the aerodrome or football field but the log book indicated a total of some 78 flying hours Component parts are still in existence

HELICOPTER W 6

Designed and constructed by Messrs G & J Weir Ltd

Chief Designer—Mr C G Pullin
Test Pilot—Mr R A Pullin

Brief Specification

Two seater tandem fuselage carrying outriggers on either side of the fuselage supporting the three bladed rotor hubs Cyclic and collective pitch control Rotor diameter 26 feet running at 275 r p m Powered by Gipsy VI Series II engines, blower cooled by Weir Fluid flywheel included in transmission line Constant speed unit fitted to rotor and automatic change-over to autorotation

All-up weight 2360 lbs (unfaired)

Design commenced in October 1938 and made first flight October 27th 1939 This was the world's first successful two seater helicopter On the 28th October 1939 the machine established a further record by carrying two passengers, besides the pilot

Maximum speed was not checked owing to the wartime restrictions on airfields and the test flying was confined to waste land at the Argus Foundry, Thornliebank, Glasgow It was estimated that the speed in a closed circuit was in the region of 80 m p h with a calculated maximum of 90 m p h Rate of climb at 25 m p h was 650 ft /sec

The machine could fly forwards backwards, sideways and rotate about the yawing axis

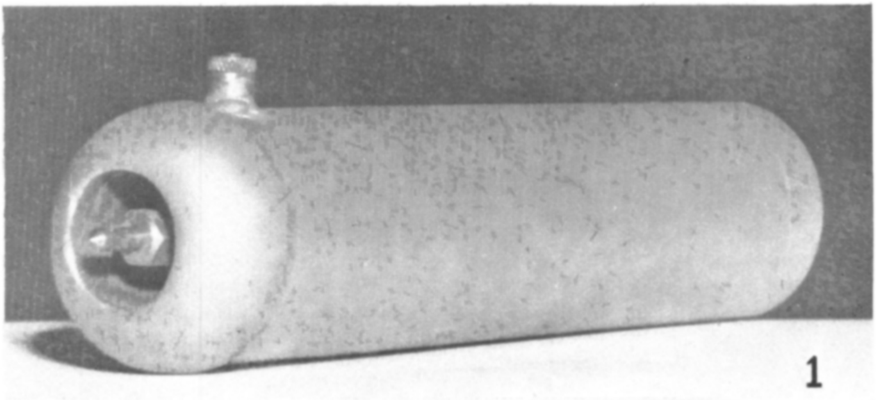
Flight tests were in progress from October 27th 1939 to July 1940 when the Department was disbanded owing to the unfavourable turn of the war A total of some 70 hours flying was recorded

The component parts of this aircraft are still in existence but the Gipsy engine was installed in the Cierva W 9

59 (top) *A small ram jet unit for experimental test (Made to drawings and instructions issued by the Aircraft Jet and Rocket Corp U S A)*

60 (centre) *End view of ram jet unit depicted in 59 The stub on the left hand side is for mounting on the rotor a m Fuel is contained in the surrounding jacket*

61 (below) *A jet unit of the impulse type Note the flap valves at intake end (Made to drawings issued by the Aircraft Jet and Rocket Corp U S A)*



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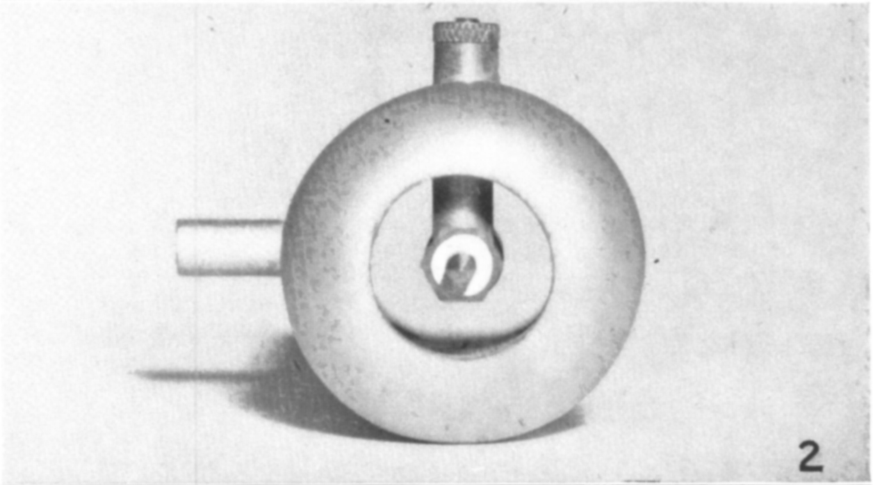

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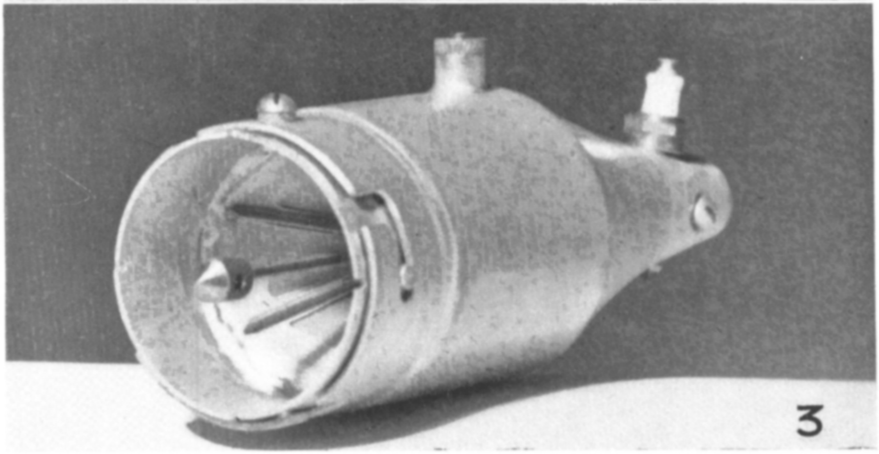

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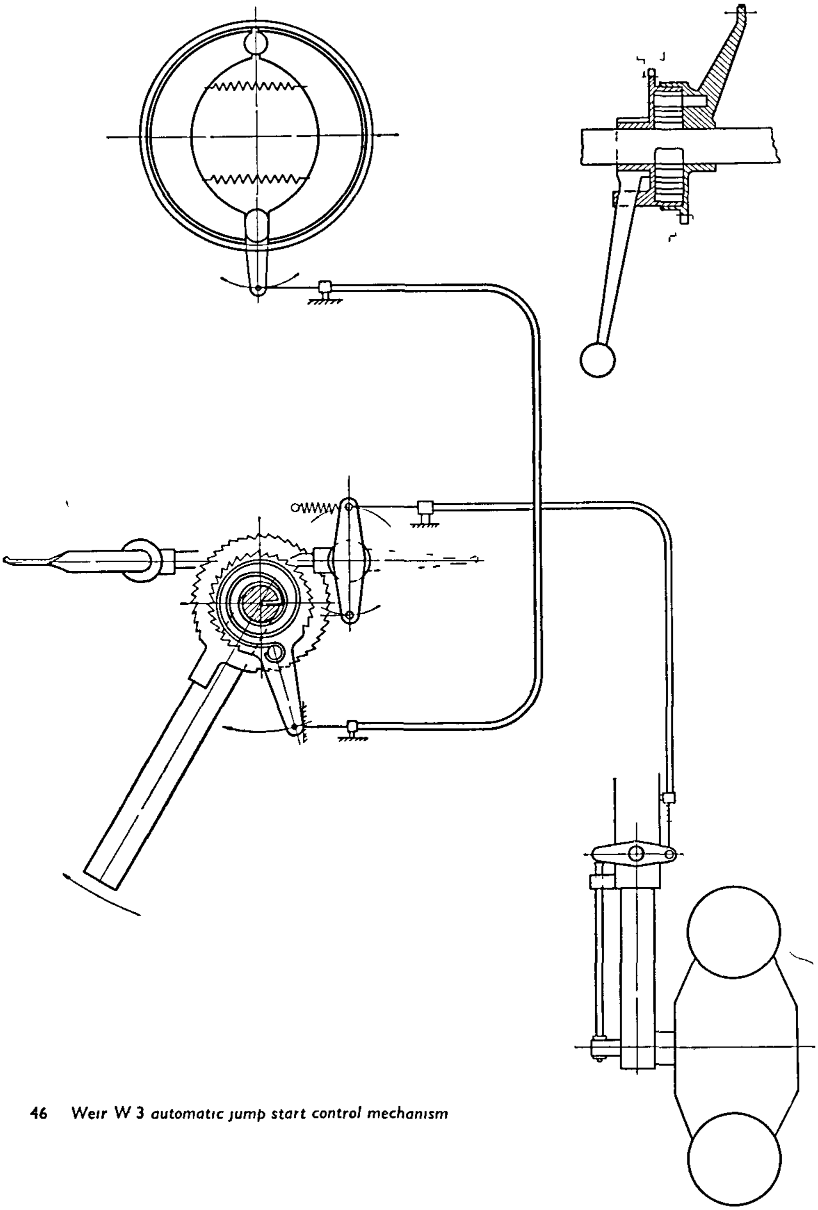
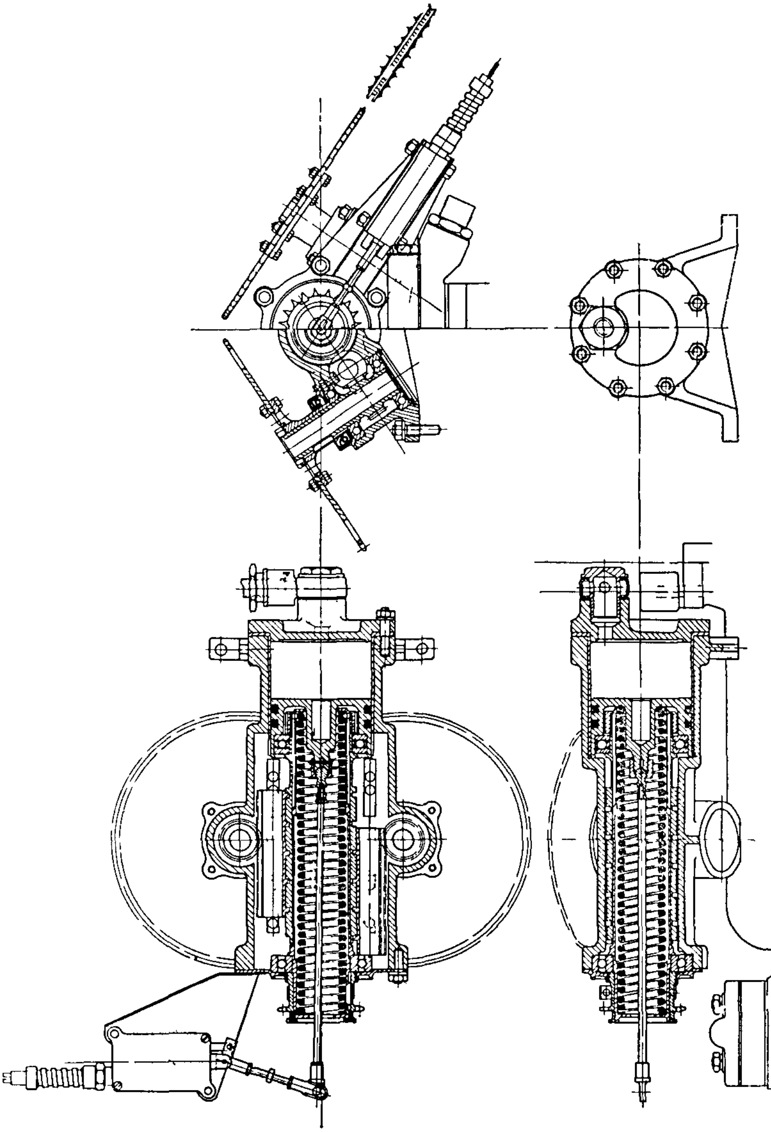
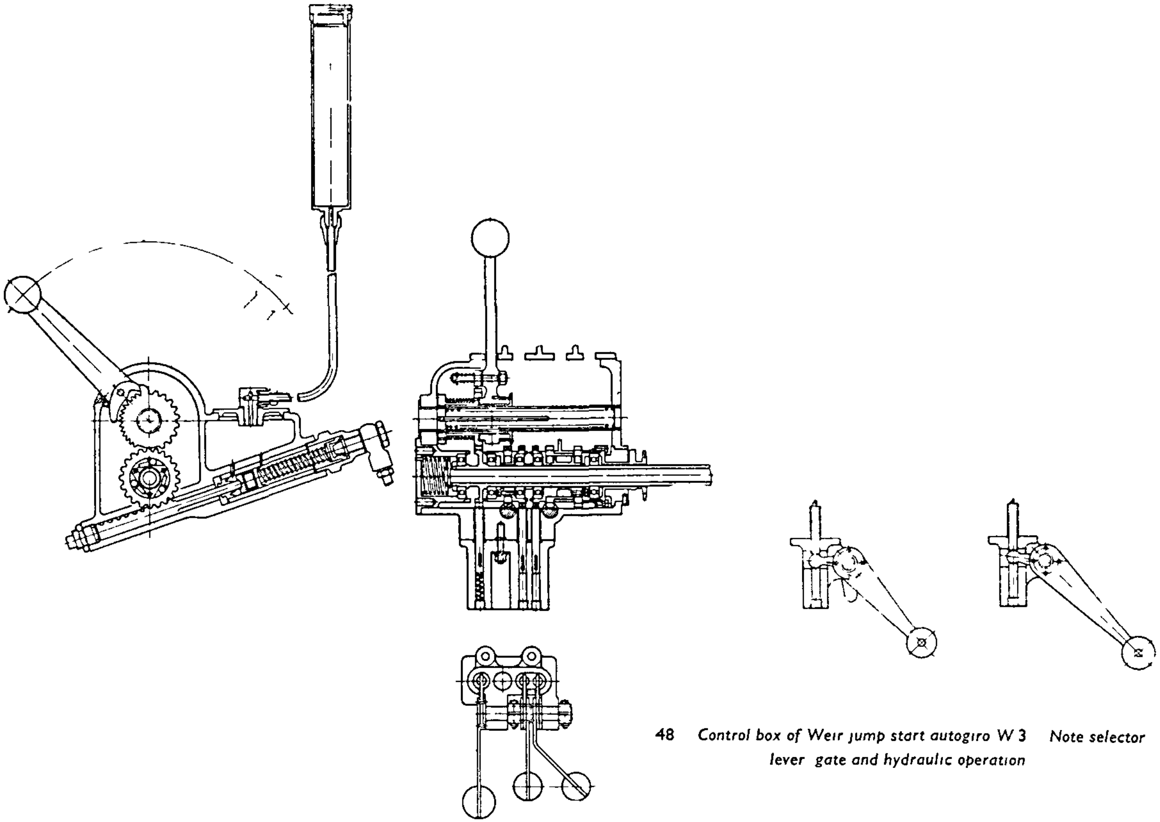


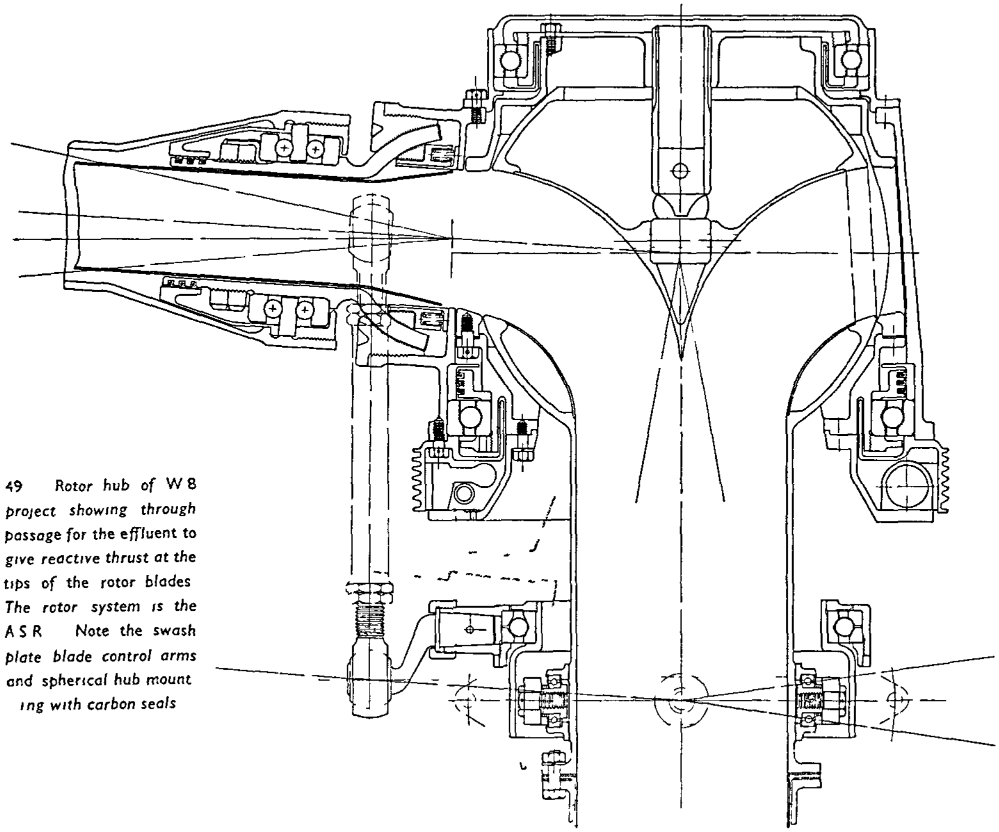
46 Weir W 3 automatic jump start control mechanism



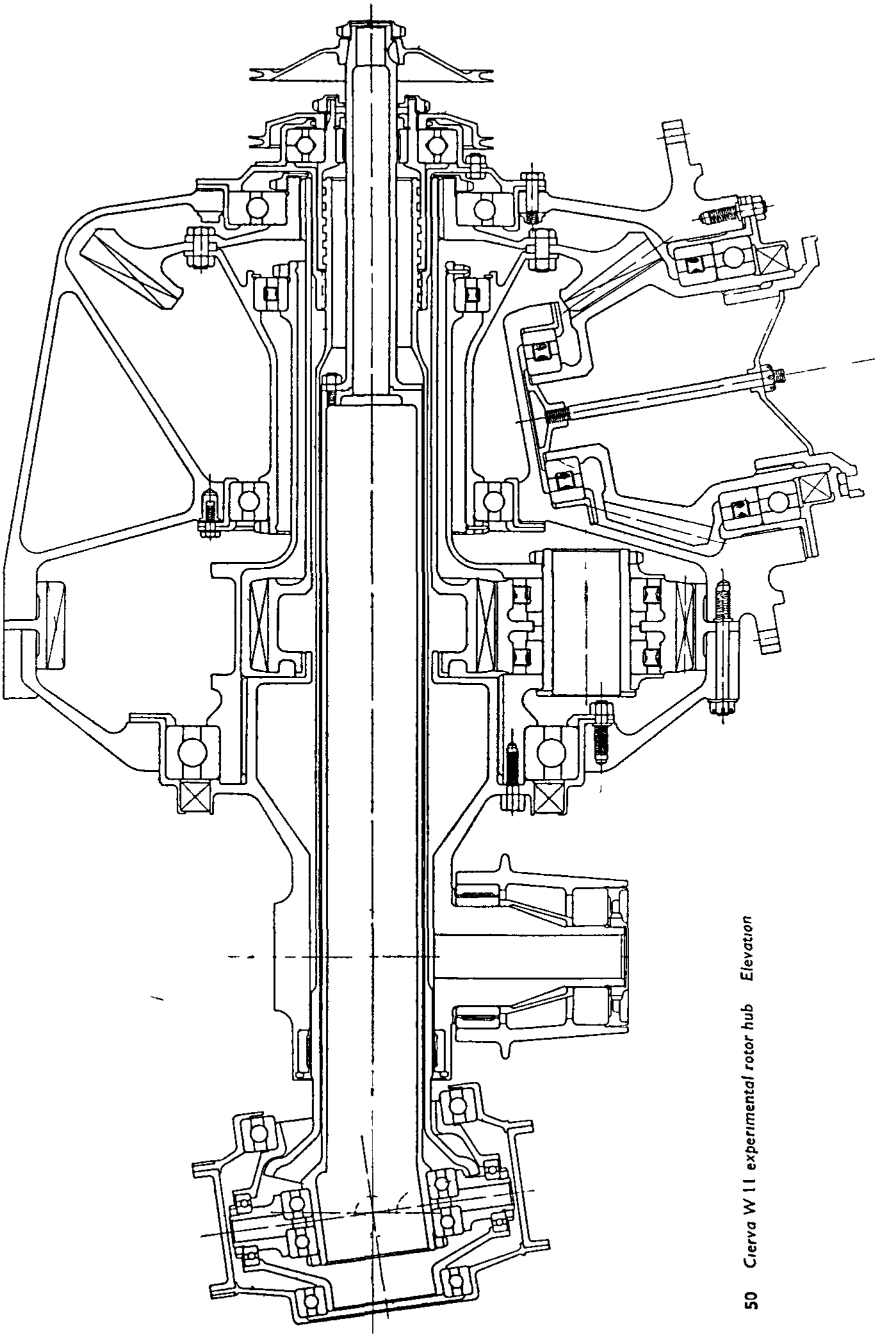
45 *Weir W 6 control box with hydraulic change over device to autorotation on rotor speed change*



48 *Control box of Weir jump start autogiro W 3 Note selector lever gate and hydraulic operation*

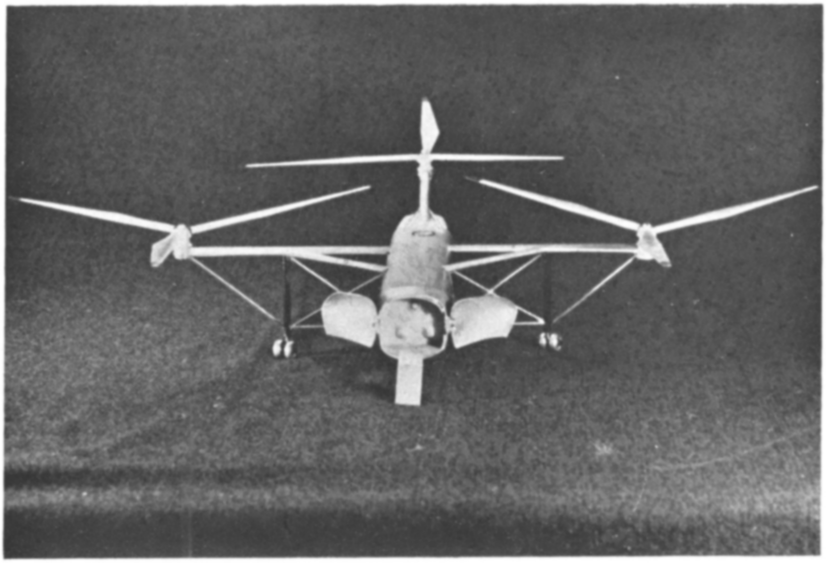


49 Rotor hub of W 8 project showing through passage for the effluent to give reactive thrust at the tips of the rotor blades The rotor system is the A S R Note the swash plate blade control arms and spherical hub mounting with carbon seals



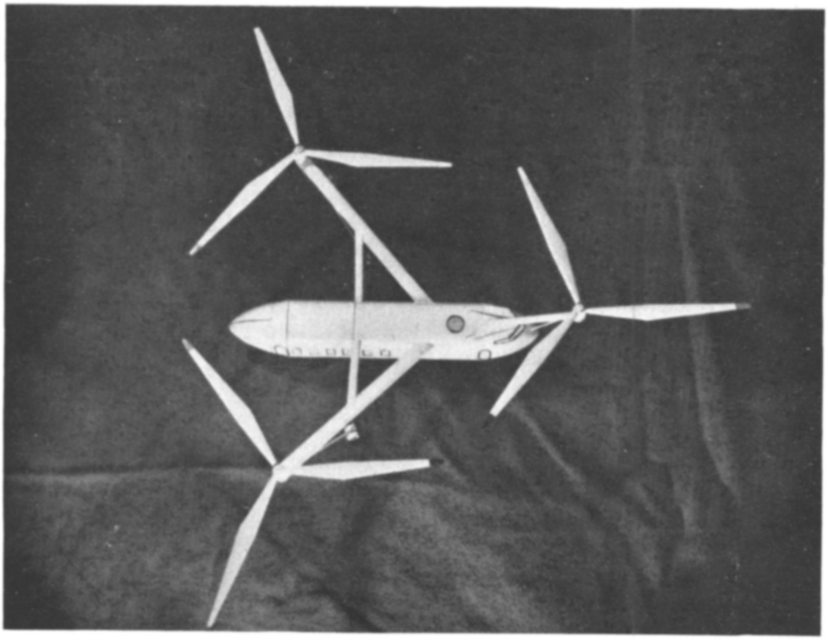
50 *Cierva W 11 experimental rotor hub* *Elevation*

51 W 11 Air Horse model The full scale machine is now under construction With Rolls Royce Merlin engine this aircraft will have a payload of three tons

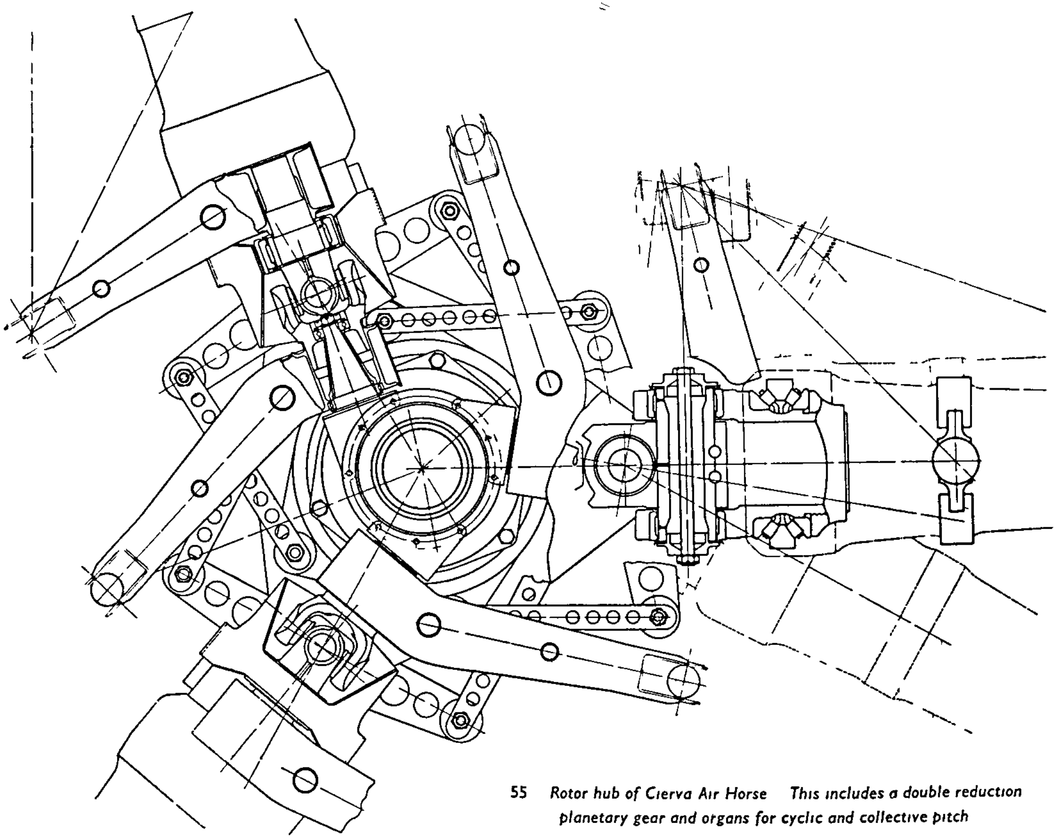


52 Cierva Air Horse freighter version Note rear loading doors and ramp

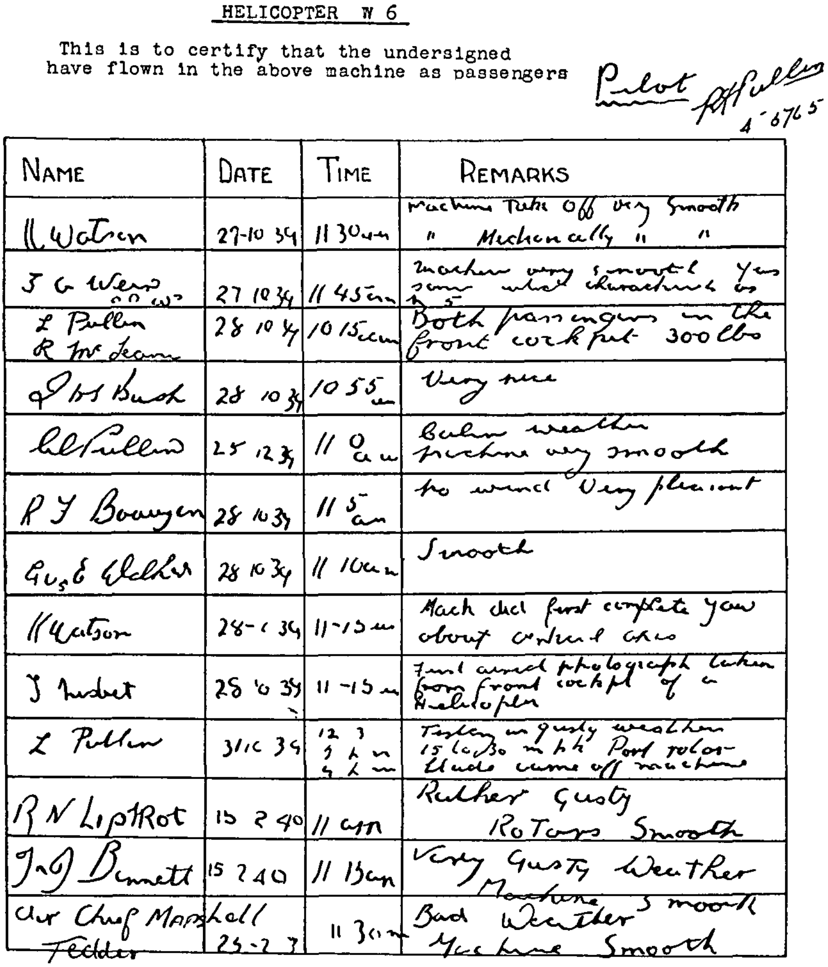
53 *Cierva Air Horse (W 11) as a 24 passenger machine excluding crew*



54 *Plan of Cierva Air Horse The air duct for engine cooling will be noted on the top front end of the fuselage*



55 *Rotor hub of Cierva Air Horse* *This includes a double reduction planetary gear and organs for cyclic and collective pitch*



HELICOPTER W 6

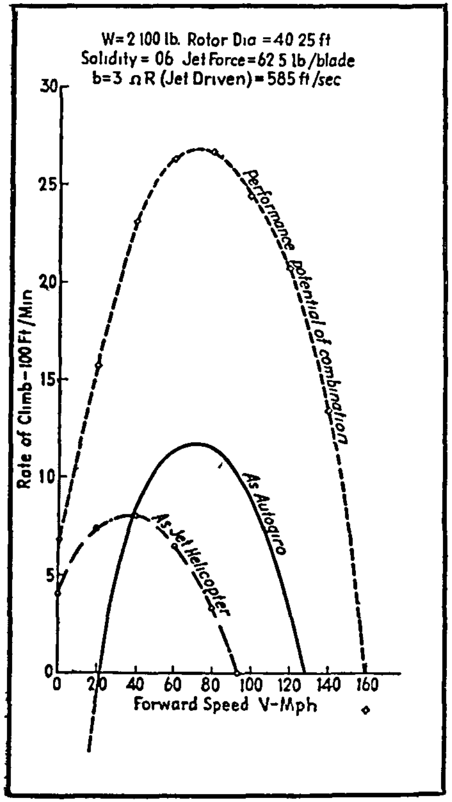
This is to certify that the undersigned
have flown in the above machine as passengers

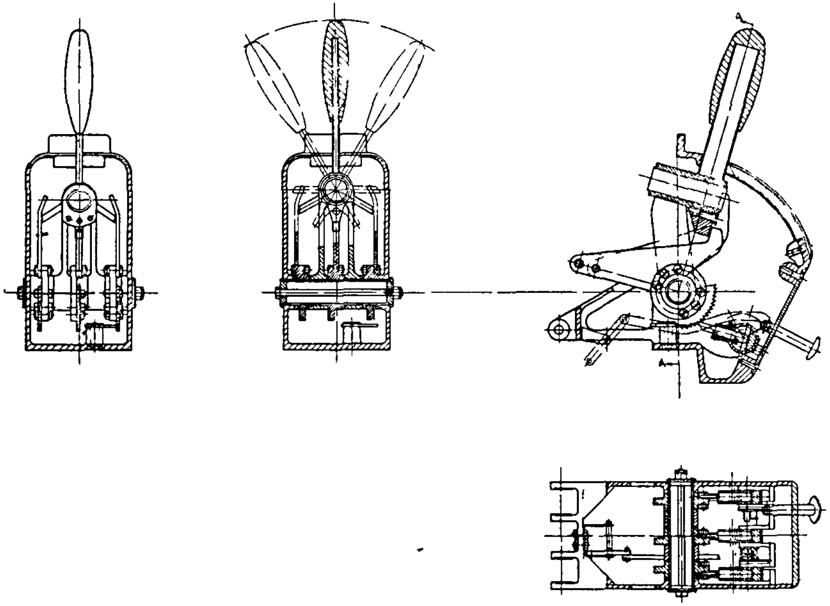
Pilot [illegible] Pullin
4-6765

NAME	DATE	TIME	REMARKS
H Watson	27-10 39	11 30 am	Machine take off very smooth " Mechanically " "
J G Weir	27 10 39	11 45 am	Machine very smooth Yaw some what characteristic as [illegible]
L Pullin R McLean	28 10 39	10 15 am	Both passengers in the front cockpit 300 lbs
[illegible] Bush	28 10 39	10 55 am	Very nice
[illegible] Pullin	25 12 39	11 0 am	Calm weather machine very smooth
R J Bowyer	28 10 39	11 5 am	No wind Very pleasant
[illegible] Walker	28 10 39	11 10 am	Smooth
H Watson	28-10 39	11-15 am	Mach did first complete yaw about central axis
J Nisbet	28 10 39	11-15 am	First aerial photograph taken from front cockpit of a Helicopter
L Pullin	31/10 39	12 3 3 h m 4 h m	Testing in gusty weather 15 to 30 m p h Port rotor blade came off machine
R N Liptrot	15 2 40	11 am	Rather gusty Rotors Smooth
J A J Bennett	15 2 40	11 15 am	Very Gusty Weather Machine Smooth
Air Chief Marshall Tedder	25-2 [illegible]	11 30 am	Bad Weather Machine Smooth

56 (above) Record of passengers carried on Weir W 6 helicopter It will be noted that the first passenger was carried on 27/10/39 On the following day the machine was flown with two passengers and pilot Many well known names are included in the list

57 First aerial photograph taken from a helicopter The group includes the designer and his staff outside the hanger on 28/10/39





47 Control box of Weir jump start autogiro Note selector lever and gate

58 *Curves showing autogiro with jet assisted rotor Project of The Autogiro Company of America (by kind permission of Mr Paul Stanley Chief Engineer Autogiro Company of America and as illustrated in the U S A magazine AVIATION*