SEVENTH LECTURE 1947

Some Work with Rotating-Wing Aircraft *

By O L L FITZWILLIAMS, B A

A lecture illustrated with slides and delivered before the Helicopter Association of Great Britain on Saturday, 25th October, 1947, at Manson House, 26, Portland Place, London, W 1

H A MARSH, A F C , A F R Ae S , IN THE CHAIR

INTRODUCTION BY THE CHAIRMAN

Ladies and Gentlemen,

It is my privilege to introduce to you today MR FITZWILLIAMS, whose subject is " Some work with Rotating Wing Aircraft "

MR FITZWILLIAMS is a founder member of the Helicopter Association and a member of our Council and has been engaged on various aspects of rotating wing development over the past nine years, first with Mr PULLIN at Messrs G & J Weir Ltd , and later with Mr HAFNER at the Ministry of Supply He is now Helicopter Engineer of the Westland Aircraft Company

During the latter part of his time with the Ministry he was in charge of the rotating wing section of the Airborne Forces Experimental Establishment at Beaulieu I understand that this period supplies the bulk of the material for his talk and I feel sure we shall find it both interesting and entertaining

On behalf of the Association I extend a cordial welcome to our guests

MR O L L FITZWILLIAMS, B A

Mr Chairman, Ladies and Gentlemen,

My talk this afternoon consists of brief descriptions of two rotating-wing aircraft produced in Germany during the war, followed by a more lengthy discussion on the engine-off landing of helicopters, and some concluding remarks about the work which we now have in hand at Westland Aircraft

We still have a great deal to do before completing our conversion of the S-51 helicopter and this work cannot yet be discussed in detail, but by the middle of next year I hope that we will be ready with a full description

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of the British S-51 and of its possibilities for future development In the meantime the assortment of subjects which I have chosen for my talk this afternoon may be regarded as a kind of hors d'oeuvre before the more substantial dishes which may be expected in future, and I hope you will find it sufficiently interesting for a start

FOCKE-ACHGELIS Fa 330

The first of the German aircraft which I am going to discuss is the Focke-Achgelis Fa 330—which is the proper name for the German autogyro kite for submarines The kite is quite well known now, although few people have actually seen it fly, but information about it became available only after the war and you can imagine our surprise when the contraption arrived at A F E E in August, 1944 With it were some odd blades and tail surfaces and a note, saying that it had been found on a captured submarine and asking us to put it together, find out how it worked and, if possible, fly it The photograph shows the fuselage unfolded and with the tail surfaces stuck on, and it did not look very encouraging (Fig 1)

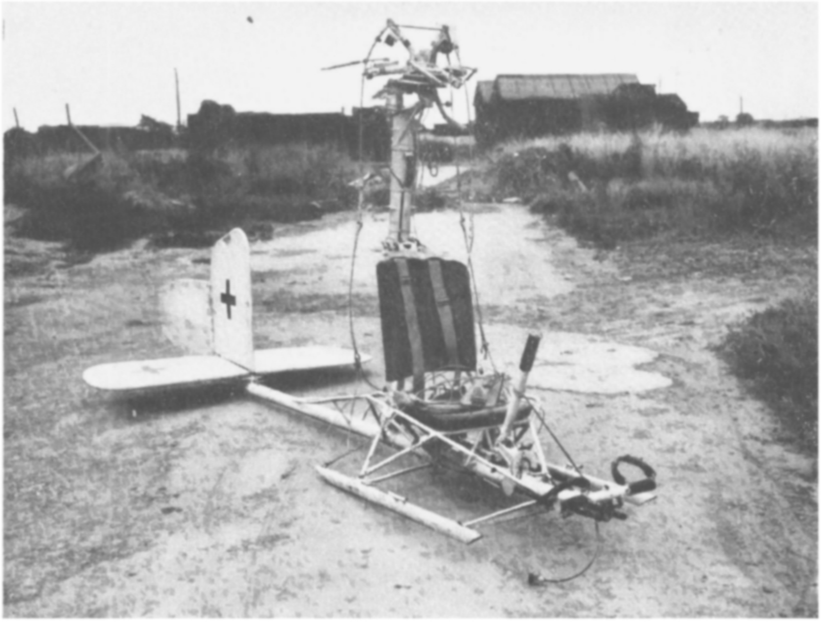

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Fig 1 Fa 330 Kite—without blades

The fuselage was in a very bad state of repair and there was a large bullet hole through the main upright member and the control rod which this member contains The blades were also in bad condition, and of the six received one was bent at the root while the others were full of holes and set at all sorts of angles The wires hanging down from the head are inter-blade bracing cables and are shown in their proper position, with the blades mounted, in Fig 2, which was taken after the whole kite had been repaired and re-conditioned

Although later flight tests showed the kite to be as well designed aerodynamically as in detail, it was at first regarded with great suspicion and I remember that we had quite unfounded doubts as to whether it had ever been flown at all Moreover Mr Hafner and almost all of the rotary wing staff of the A F E E decamped to Bristol at this point, leaving Mr Leonard Liscombe and myself with the single helpful suggestion about flying the kite from a trailer towed by a jeep, and a large number of derisive remarks about the possibility of our doing so without breaking at least the kite and probably the pilot as well

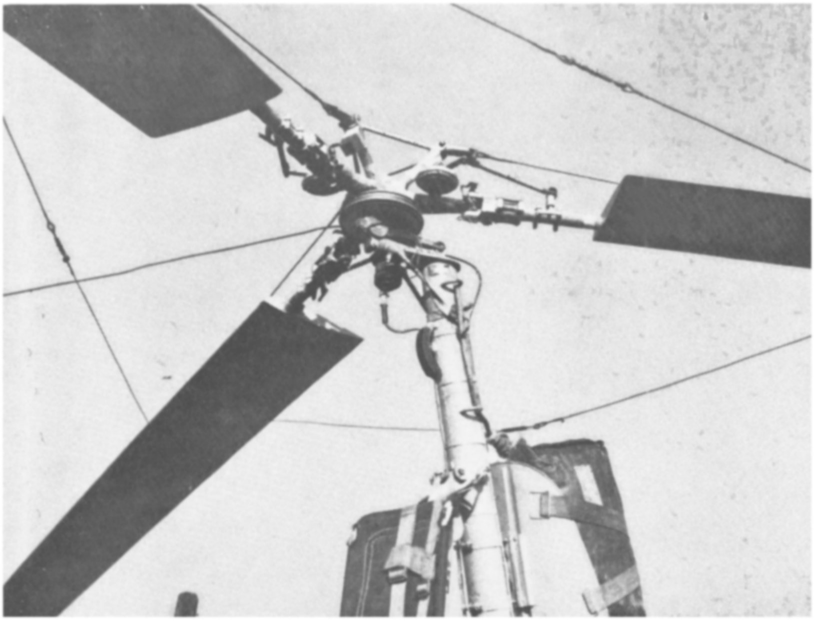

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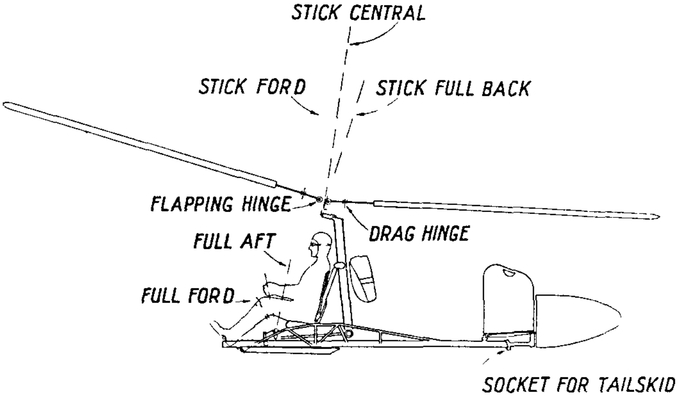
Fig 2 Fa 330 Kite—Blade Assembly

The general arrangement of the kite is illustrated in Fig 3 Its detail design has often been described but it is so ingenious that I hope I may be forgiven for briefly mentioning again some of its outstanding points For stowage purposes the blades and tail surfaces are quickly detached and the back of the seat is unclipped from the main upright member so that this can be folded back over the tail The seat is then folded back and also the control stick Finally the landing rails are folded close in to the sides of the fuselage, which can then be inserted into the cylindrical watertight container in which it is stowed on the deck of the submarine The blades and tail surfaces are stowed together in another container

The most spectacular feature of the kite is that in addition to the ordinary tow cable quick-release there is a handle beside the pilot's head which he can pull if attacked in the air The consequences of doing this are that the tow cable is released and at the same time the whole rotor flies off, pulling with it the top of a parachute to which it is attached by a breaking-tie The parachute is normally stowed in the dish-like tray behind the main upright and its rigging lines are attached to a point on the pilot's harness, so that when the parachute is open it supports the pilot who is still attached to the rest of the kite by means of his safety belt When this belt is undone the remaining structure falls away and the pilot is then free to drown in a conventional manner



GENERAL ARRANGEMENT OF FA 330, ROTARY WING KITE

Fig 3

Certain features of the kite gave rise to considerable doubts as to the proper method of handling it—for instance, the fuselage is fitted with a socket for a tailskid and it was some time before we realised that this has nothing to do with operation from a submarine but is used in conjunction with a very tall undercarriage developed for training purposes on land

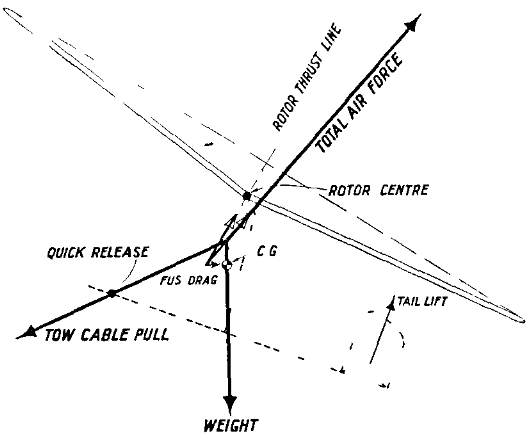
Also we knew nothing of the stability characteristics of kites, except that model autogyro kites are often highly unstable, and if it had been difficult to fly it would have been most unpleasant to attempt to take off and land on a relatively narrow trailer being towed down a runway, which was the only method open to us without extensive alterations to the kite

Thus the first problem was to find out something about the behaviour of rotary-wing kites in general and of this one in particular before embarking on a set of flight trials which might wreck the only available example There are probably much more elegant methods of examining this problem than the one I am about to describe but our rather crude method, although far from being an exact calculation, does give a fairly comprehensive and easily understood picture of the behaviour of rotary-wing kites in general—as well as results which are of the right order as regards the magnitude of the forces acting on them

To begin with there are only three major forces acting on a kite, namely the Total Air Force, the Tow Cable Pull, and the Weight, as shown in Fig 4

The Total Air Force is made up of the Rotor Thrust, which can be assumed in this case to act through the rotor centre at right angles to the rotor, and the Fuselage Drag which is horizontal and which we assumed to act through the C G The weight acts vertically through the C G and the moment effect of the tail lift can be included with reasonable accuracy by assuming the C G to be displaced a suitable distance from its true position, neglecting the effect of the tail lift on the linear balance of the major forces The Tow Cable Pull, of course, acts through the Quick-Release attachment of the cable to the fuselage

We know the positions of the rotor centre, C G and quick-release point in the fuselage so that if we can find some means of determining the magnitude and inclination of the major forces acting in a given condition of flight, we can soon determine the corresponding fuselage attitude, stick position, etc, by a trial and error process The trial and error part is quite simply done with the aid of a transparent copy of the dotted parts of Fig 4, which is moved about over a series of trial force diagrams until the position of equilibrium is found Alternatively, we can first assume a given fuselage attitude and stick position—the latter gives the inclination of the rotor thrust relative to the fuselage when a small correction is made for flapping—and then proceed to determine the wind speed at which equilibrium occurs



FORCES ACTING ON KITE

Fig 4

This process is apt to be tedious but it is very easy if we have some simple means of obtaining the magnitude and inclination of the major forces In casting about for something of this sort, we came across test results giving the polar force co-efficient diagrams for the C 30 autogyro rotor and for Mr Hafner's small Rotachute rotor and these rotors were sufficiently similar to each other and to the kite rotor to justify us in taking a mean curve as a suitable basis for our estimates

This curve, which is shown in Fig 5, indicates a typical relation between the Lift and Drag Co-efficients of a gyroplane rotor and is very convenient for our purpose, because having assumed that the rotor thrust is always perpedicular to the rotor, it follows that if the rotor is inclined backwards at an angle of θ then the rotor thrust is also inclined backwards at the same angle and the magnitude of its co-efficient can be read direct from the diagram

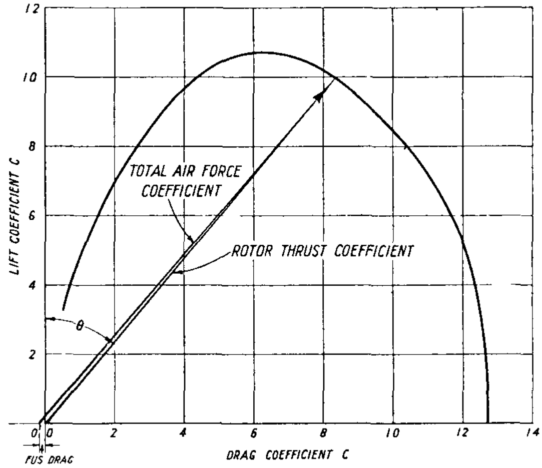


Fig 5

POLAR FORCE COEFFICIENT DIAGRAM FOR KITE

Moreover, since the fuselage drag is always horizontal, its co-efficient, based on disc area like the others (the diameter of the rotor is 24 ft), can be set off to the left as shown, so that for a backward inclination of the rotor we have immediately the backward inclination and magnitude of the Total Air Force co-efficient measured from the new origin 0′ The fuselage drag actually is so small that in most cases it could be neglected

Knowing the inclination and magnitude of the rotor thrust and Total Air Force for any condition of flight, and also the magnitude of the weight acting downwards, we only require to know the magnitude and direction of the Tow Cable Pull in order to draw the complete force diagram But we can find this out quite easily if we take 0′ as the origin for a new graph on which we can re-plot the curve shown in Fig 5, this time not in terms of the co-efficients which are independent of wind speed but in terms of actual forces for a number of different wind speeds shown in Fig 6

Fig 6 is, then, a polar diagram of actual forces so that if we take a wind speed of, say, 39 ft /sec and consider the Total Air Force to be inclined backwards along, say, 0′A, we can immediately complete the force triangle by marking off a vertical distance 0′B equal to the weight so that BA now gives the magnitude and inclination of the Tow Cable Pull

Two rather important things are immediately noticeable from Fig 6 Firstly, it is obvious that if the kite is flown with the stick far forward, the rotor thrust will be only slightly inclined backwards The forces acting on the kite are then defined by a point on the lower left hand part of the curve for the particular wind speed Also, as the stick is brought back, the point defining the forces acting on the kite moves from left to right along the given curve

Therefore, as the stick is brought back, the tow cable, which may have started at an inclination even below the horizontal, gradually rises until it reaches the angle defined by a point such as C, where its upward inclination is a maximum for the given wind speed It is not, of course, surprising that at a given wind speed there should be a particular stick position giving the maximum kiting performance, but it is rather disturbing for a pilot to contemplate flying an aircraft which, towed at a constant airspeed, will rise on the tow cable when the stick is pulled back part of the way and fall at ever-increasing speed when the stick is pulled back the rest of the way Especially when flying on a short tow cable you can imagine the embarrassment of a pilot who finds himself descending with no means of knowing whether he should push the stick forward or pull it back or just sit and wait until the wind freshens

Fig 6 also illustrates the fact that whereas the rotor of a normal rotary wing glider supports only the weight of the aircraft, that of a kite supports a large part of the tow cable pull as well Moreover, the forces which could be developed by the rotor at quite ordinary wind speeds appeared to be far larger than the fuselage of the Fa 330 was designed to withstand

To investigate these points further it was decided to work out not only the take-off and landing behaviour, in which the stick was found to be roughly central with the fuselage in a very tail-down attitude, but also to examine the kite's behaviour with the stick hard back, in which condition the maximum rotor forces and instability could be expected

We have already noticed that as the stick is pulled back, the point defining the forces acting on the kite moves from left to right along the curve for that particular wind speed At high wind speeds, when the tow cable is pulling the kite's nose strongly downwards, we find that there is a limit to the backward inclination of the rotor even with the stick hard back, so that the force-point can only move a certain distance along each curve If these limiting positions are joined up we find there is a definite limit to the forces which can be imposed on the kite and a typical limit of this kind is shown by the thick curve in the upper part of the diagram This curve is kinked because it includes an allowance for the lift of the tailplane, which is assumed to stall at the angle indicated by the kink

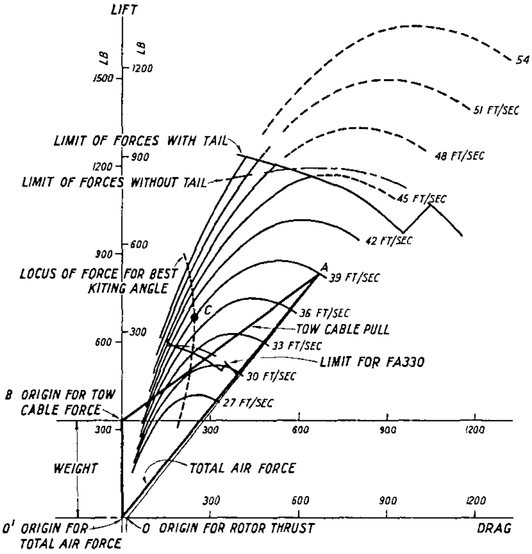


Fig 6

POLAR DIAGRAM FOR KITE TRIANGLE OF FORCES

At low wind speeds the forces on the kite do not reach the limit curve so that the tow cable angle will still increase when the stick is pulled back part of the way, and decrease again when the stick is pulled back the rest of the way If the stick was actually pulled hard back the result would be a very unpleasant tail slide

At higher speeds, where the forces on the kite reach the limit curve, a momentary equilibrium could be obtained, but the condition would be unstable because the limit curve is reached after the inclination of the tow cable has passed its maximum In this condition, if the kite is disturbed in such a way that its nose is pulled down slightly, the change in attitude will correspond to a larger inclination of the tow cable so that the kite will start to move forward against the wind and at the same time the rotor thrust and speed will both drop off After a short interval, if the pilot keeps the stick hard back, the nose will rise again and the kite will drift backwards with the wind while the rotor thrust and speed build up again to an amount which will overshoot the normal force limit and the nose will be sharply pulled down again so that the unstable movement will build up Except on a general basis I have not examined this oscillation very carefully, but anyone who has played with model autogyro kites will recognise it and I think you will agree that it does not represent the best condition for calm observation of enemy shipping

Owing to an oversight in our preliminary examination, we thought at first that the force limit in the upper part of this diagram represented the characteristics of the Fa 330 and the huge forces and unpleasant behaviour which it indicates are not only a warning to designers of future kites but they also caused us to do the first tests in a very gingerly manner with the kite securely tied down However, these tests immediately showed that the Fa 330 is really a very tame affair and on looking for an explanation we found that Dr KLAGES, the designer, had very carefully arranged the back stop on the control stick so that the flight characteristics are actually those shown by the limit curve in the middle of the diagram This curve indicates that, in almost any wind in which the kite can fly, it is stable fore and aft and has its maximum performance with the stick hard back Also in this condition the rotor thrust and speed are substantially constant irrespective of wind speed These characteristics were confirmed in flight tests, and with S /Ldr KRONFELD at the controls the kite soon showed itself to be everything a submarine commander could wish for as an observation platform

The kite required fairly dextrous handling when flown on a short tow cable, but was quite docile on the longest rope we could manage (22 ft) and KRONFELD was able to let it fly hands-off for appreciable periods on this length of cable in spite of its slight lateral instability

I have here an illustration showing KRONFELD, in his usual role of intrepid birdman, braving the elements in this curious contraption (Fig 7)

It is doubtful if rotary wing kites will ever be a serious requirement likely to weigh heavily on the members of this Association, but the effort spent on this one may not have been wasted Not long before I left Beaulieu we received from Australia a request for advice on the possibility of operating these kites from fishing vessels, for spotting shoals of fish Although a kite could be used for this purpose I am inclined to think it would be more of a trouble than a help But the ease with which it could be landed and

Fig 7 Kronfeld testing Fa 330 on short tow cable

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launched, from a tiny platform only a few feet square and in all sorts of weather, does suggest that for applications of this sort there would be some benefit in developing a kind of combination kite and helicopter as shown diagrammatically in Fig 8

The main requirement of such an aircraft would be the ability to develop a lift substantially greater than its own weight This is, of course, easily done even without an engine provided there is ample wind, and it is necessary in order to keep the tow cable tight when the platform is moving up and down The most difficult case would be when there is a heavy swell in the calm air

I believe it would not be very difficult to meet this requirement and air observation would then be possible even in calm weather, while in windy weather the aircraft could sit for hours on the end of the cable at no cost at all Moreover it could always start its engine and drop the cable at will to go cruising about under its own power

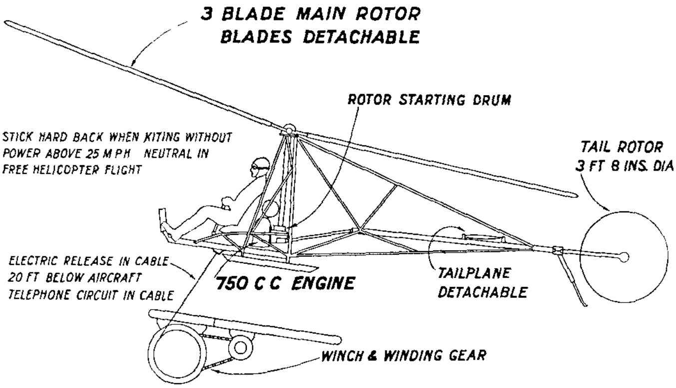

Fig 8

SUGGESTED COMBINED KITE AND HELICOPTER

I picture the tiny landing platform, with its attached winch, as projecting from the side of the ship so that when the aircraft wished to hook on again it could drift slowly backwards low down over the platform, with about 20 ft of cable dangling from its nose It would hover while an operator on the platform hitched the dangling cable on to the main tow rope and it would then back up until the cable became tight The power could be shut off as the aircraft began to kite and finally to rise up on the tow cable for a further spell of cheap spotting

Observation of the kite's behaviour leads me to suppose that landing and take-off with this arrangement would be quite a practical business on a fishing vessel and it may be that it could be developed for more general application to helicopter's operating at sea

FOCKE-ACHGELIS Fa 223

I would like now to tell you something about another aircraft which came to us at Beaulieu from the same stable as the kite This was the big Focke-Achgelis F a 223 helicopter shown in Fig 9

The prototype was built in Bremen in 1940 and it was not only highly successful as a helicopter but it also met requirements for anti-submarine patrol, armed reconnaissance, air sea rescue, cargo transport, etc, which could be met by very few of our present-day helicopters Moreover it did this at a time when other helicopters were either on the drawing board or else in a strictly laboratory stage, and it was not even considered to be an experimental aircraft to any important extent, since its design is very firmly based on that of the smaller FW 61 helicopters which had been flying successfully since 1937

Thirty F a 223's were ordered by the German Air Ministry but construction work was limited to twenty-five, of which the majority were destroyed by bombing in various stages of manufacture Only three remained serviceable when the war ended and one of these was destroyed by its pilot The remaining two were delivered to the Americans at Ainring in May, 1945, and one, the 14th production aircraft, was subsequently flown

Fig 9 Fa 223 Helicopter

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by its German crew, via Paris, to the A F E E at Beaulieu, where it arrived in September, 1945, having performed the first crossing of the English Channel by a helicopter

Fig 9 gives a good view of the arrangement of the F a 223 and you can see the cooling air intake grill just forward, and the outlet slit just aft, of the 1,000 h p Bramo Fafnir engine, which is mounted, facing forwards, in the centre section of the fuselage The rotors are driven by long transmission shafts connecting a right-angle drive on the front of the engine to double-reduction gears in each rotor head

The undercarriage struts and the two main top members of each outrigger were round tubes but the remaining members were of roughly streamline section, and although a good deal of power is required to drag all this bridgework through the air, the F a 223 could slip along at 95 knots when in a hurry and cruised normally at 65 knots The fuselage provides accommodation for pilot and observer in the nose and for a navigator and one other crew member in a separate compartment behind the cockpit

The undercarriage is interesting because it serves two quite distinct purposes Normally the fuselage is horizontal and the aircraft sits on its main and nose wheels with the main wheels behind the C G , but if the tail is pulled down it will rest equally happily on the tailskid and the main wheels, which are then in front of the C G In this attitude the rotors have quite a large angle of incidence of 12° relative to the ground In autorotation the aircraft would land like this and although its engine-off landing speed is fairly high—of the order of 35-40 knots—the huge drag of the inclined rotors results in quite a short landing run

Fore and aft control is by normal blade feathering, which tilts both rotors forwards or backwards together Yawing control is obtained in hovering flight by tilting one rotor forward while the other is tilted back, but the pedals also operate the rudder and this does most of the work in forward flight, thus avoiding the adverse rolling moment which results from differential tilting of the rotors in forward flight, when they act more like ailerons than as a yawing control When the aircraft was turned in hovering flight by application of rudder control the turning movement resulted in a large increase of effective disc area so that the machine climbed quite rapidly without any increase of power This corresponds to the epicyclic arrangement of rotors mentioned by Dr BENNETT in his lecture

Lateral control is obtained by increasing the lift of one rotor and decreasing the lift of the other, but there is no means of increasing or decreasing the lift of both together except by the rather indirect means of changing the throttle setting and waiting for the rotors to speed up or slow down This control is sluggish and requires much foresight when manoeuvring in gusty weather near the ground, although because of its symmetrical arrangement and simplified controls the F a 223 was apparently easier to learn to fly in the initial stages than most of our present helicopters

In the fore and aft direction it had the same instability which is familiar, in all directions, to pilots of single-rotor helicopters, and in the few flights I had as a passenger I did not notice that the large tailplane resulted in any marked improvement in forward flight, at any rate at moderate speeds On the other hand it was quite strongly stable about the rolling axis so that in calm air an angular disturbance about this axis, or a lateral movement of the aircraft, would soon be damped out if the controls were held central

Watching the behaviour of the aircraft one was, however, impressed by the fact that stability of this kind does not necessarily mean that the aircraft has any tendency to keep still in gusty weather On the contrary, the rotors were very sensitive to changes in airflow, and in gusty air they bobbed up and down in a quite impressive manner, requiring sharp control movements to keep the aircraft level

Under operational conditions the F a 223 was flown at an all-up weight of 9,500 lb , which included 2,500 lb of disposable load, a proportion which compares favourably with most present helicopters On a weight per horse power basis it was, however, a rather poor performer, largely because of its very high disc-loading which, at this weight, was 3 9 lb /ft ^{2} Nevertheless, I imagine the KELLETT XR10 and the McDONNELL, both of about the same power as the F a 223, are the only present-day helicopters carrying a normal disposable load approaching 2,500 lb , though several others could lift this weight as an overload with the help of a breath of wind The Focke, of course, could also lift an overload, flying with a disposed load of 4,000 lb , including the whole centre section, with engine, of another F a 223, the weight on the end of the cable being 2,820 lb

Although the mean blade pitch of the rotors was fixed in helicopter flight the pitch could be reduced to ensure autorotation To do this the pilot could operate a two-position lever which was connected to a highly amusing mechanism which had ramifications in all parts of the aircraft When the lever was raised it caused the engine clutch to be engaged by a hydraulic ram which also set the rotor blades to helicopter pitch When the lever was lowered the clutch was disengaged and the rotor blades returned at a controlled rate to the autorotative pitch In addition to clutch and pitch operation the mechanism changed the tailplane incidence for each condition, operated a valve allowing lubricating oil to be pumped by the engine to the rotor heads in helicopter flight, and automatically closed and locked the throttle when changing the autorotative flight The mechanism operated automatically in the emergencies of engine-failure, oil pressure failure, transmission breakage, or operation of the pre-loaded free-wheel mechanisms in the hubs Also a governor-operated cut-out in the ignition system, intended to protect the engine when suddenly de-clutched, could mistakenly operate the mechanism if the rotors were over-speeded as could happen in manoeuvres near the ceiling of the aircraft when carrying a heavy load Further complications were necessary to make taxying possible with the rotors turning above the critical change speed

Once the mechanism had operated, even voluntarily, it was impossible to regain the helicopter condition in flight and a glide landing was necessary In fact, with the high disc loading of this aircraft and the absence of any control over the blade pitch, a glide landing was essential and if there was not enough height for this purpose the operation of this so-called safety mechanism would dump the aircraft as a heap of wreckage on to the ground

This actually happened, at about 60-70 ft above the ground, shortly after the machine arrived at Beaulieu, and I was among those who were sitting in it at the time In consequence I have a strong prejudice against trick gadgets in helicopter control systems and also a rooted objection to helicopters, however light their disc loadings, which do not allow the pilot direct manual control over the blade pitch in order to cushion a forced landing

Before leaving the F a 223 I would like to call your attention to the extent of the equipment fitted to this 1939 design It had a good working position for the navigator and full radio and instrumentation, including an electric artificial horizon, also dual controls could be fitted

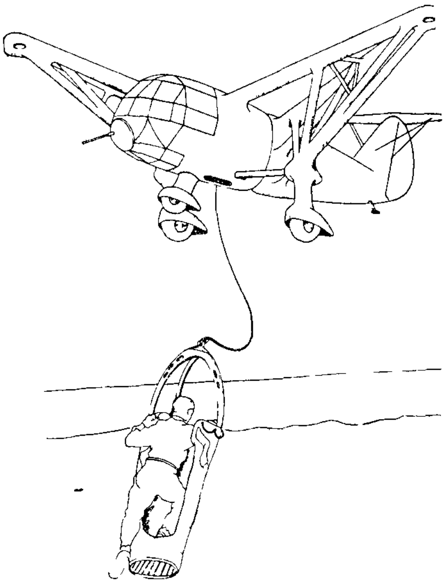

Fig 10
Fa 223—Method of air/sea rescue

A machine gun could be fitted in a standard ring in the nose, with the gunner in a prone position on the padded floor, and two 250 K G bombs could be carried on racks beneath the fuselage Also a standard 4-man emergency dinghy, inflatable from the cockpit, was stowed in the upper part of the rear fuselage

Of the specialized fittings, you have already seen how external loads were lifted on a cable suspended beneath the fuselage To aid the pilot in landing suspended loads at night, the aircraft examined at Beaulieu was fitted with a radio altimeter A powerful landing light was also fitted in the nose and this was rotatable about its horizontal axis by an electric motor

Finally, I think we can still learn some lessons from the Air-Sea Rescue equipment fitted to this helicopter Fig 10 shows the special rescue bucket floating with its rim level with the water and with a large opening in one side, into which even an injured man can swim easily Once in the bucket the injured man stands on an open grid floor, which allows the water to escape when the bucket is lifted A safety strap can be fastened across the opening and it was originally intended to provide intercommunication between the rescued person and the pilot, although I do not think this was ever fitted Fig 11 shows the way in which the rescue bucket could be hoisted through a hole in the cabin floor, right into the aircraft, so that the man can safely be taken out of it

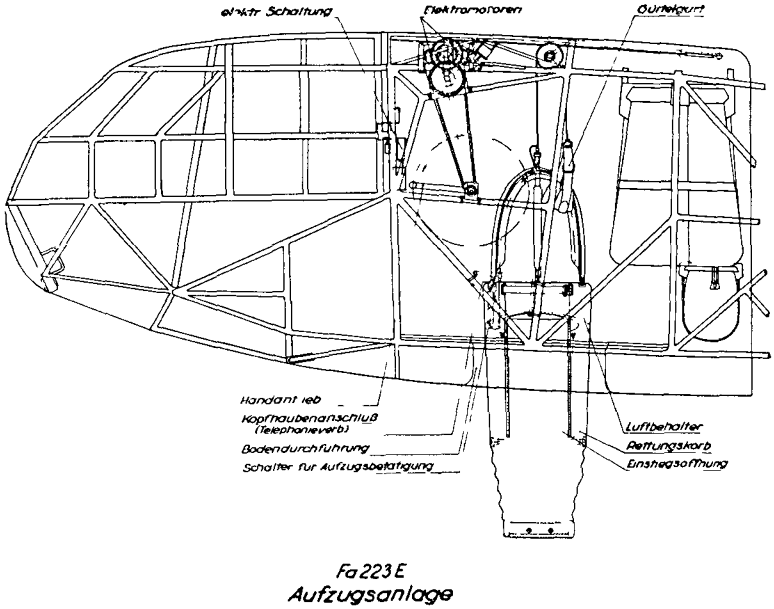

Fig 11 Fa 223—Arrangement of air/sea rescue apparatus

The F a 223 represents the first successful attempt to develop an operationally useful helicopter, and I think you will agree that considering the time and circumstances of this development, it was a very remarkable achievement

ENGINE-OFF LANDING

From these descriptions of two aircraft, which are of interest mainly for historical reasons, I turn now to a discussion of the engine-off landing of helicopters This is an aspect of helicopter flight which has a particular fascination for me because I have had the good fortune to take part in certain experiments connected with it and I believe that a study of it leads to important conclusions with respect to the possible use of helicopters on a very large scale

There is still a good deal of argument about engine-off landings and in discussing them with all sorts of people I find a diversity of views and experience which is extraordinary, considering the length of time that helicopters have been in operation The subject is made up of a number of very simple considerations which most people consider to be obvious but, probably for this reason, nobody seems to have bothered to analyse them in detail or to set them out in a logical sequence

Our present confusion arises partly because the requirements of an engine-off landing have not received adequate attention in the design of our first generation of helicopters, and partly because very few pilots have been trained *ab initio* on helicopters Thus the early pilots have found that they can pull off forced landings in a helicopter with the aid of techniques previously learnt from the aeroplane and the autogiro These techniques are familiar and their successful modification to suit the helicopter has enabled us to answer a lot of awkward questions about what happens when the engine stops, but when one watches the modern pupil being taught to practice engine-off landings by doing violent flare-outs or high speed dives followed by long floats over the ground one cannot help thinking that an essential screw somewhere wants tightening

In practice these techniques work remarkably well, but they are nowhere near what is required before the helicopter can be considered suitable for large scale use as a common means of personal transport Also their familiarity and apparent naturalness have led to their limitations being accepted as inherent limitations of the helicopter and it is now up to the designer to expose this fallacy by providing helicopters which, in the event of engine failure, can be landed as helicopters instead of as imitation aeroplanes or autogiros

Although opinion among designers may not be unanimous on this point, I believe the facts are sufficiently obvious to ensure an early improvement in the case with which engine-off landings can be made, but in general it will take some time to produce new helicopters and to modify existing ones to meet the new requirements In the meantime, before our confusion gets worse confounded by current training programmes, I think there is a need to set out and examine the considerations governing the performance of an engine-off landing, so that we can at least have a common basis for discussion of our present practice and a common understanding of the changes which may shortly be expected

To begin with, the most obvious thing about any method of performing an engine-off landing is that its primary purpose is to eliminate the downward velocity of the approach glide Therefore, during some part of the landing manoeuvre, the vertical component of the Total Air Force acting on the aircraft must exceed the weight for long enough to allow the downward velocity to vanish

During the approach glide the aircraft is in equilibrium at a constant speed so that the Total Air Force acting on its vertical and equal to the weight and the energy required to produce this force is supplied by the potential energy which the aircraft is steadily losing by virtue of its descent The supply of potential energy is, however, cut off at the same time as the descent is arrested, while the force required to do this is at the same time greater than that which was steadily maintained in the approach glide The necessary considerable supply of energy must therefore be tapped from some other source and in an engine-off landing the only other sources are the kinetic energy which the helicopter possesses by virtue of its speed along the glide path and the kinetic energy stored in the rotors by virtue of their anular velocity It therefore follows that while the downward velocity of a helicopter is being arrested there will be a reduction of the speed along the flight path or of the angular velocity of the rotors or of both and these three ways of using the kinetic energy which is available correspond to the three types of possible engine-off landings

The considerations which govern the manner in which the kinetic energy is used are illustrated in Fig 12 This illustration may look rather complicated at first, but I think it will be quite easily followed if we start with the thick arrow in the upper part of the illustration, which is a polar diagram similar to those we have discussed in connection with the Kite The thick arrow represents the motion of a helicopter in steady flight, because its length indicates the speed of the helicopter, and its downward inclination is the actual slope of the glide path, since you will notice that the horizontal and vertical scales inside the border of the diagram are marked off identically in ft /sec

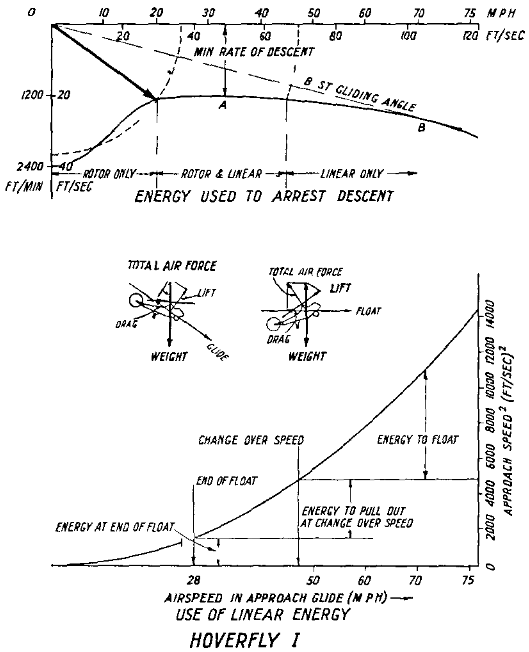

Fig 12

The arrow rests on a curve, which represents approximately the glide performance of the Hoverfly I (Sikorsky R-4b) helicopter, and you will notice that if the tip of the arrow were moved from left to right along the curve the length of the arrow would increase and its inclination would get less until we arrive at the point A where the arrow would indicate the gliding angle and flight path speed corresponding to the minimum rate of descent After this the arrow would get rapidly longer for small changes in the gliding angle until, at B, it would become tangent to the curve and would then indicate the flight path speed for Best Gliding Angle, which occurs near the top of the speed range for the Hoverfly I

Now, if it desired to eliminate the downward velocity of the approach glide by means of the kinetic energy of forward motion alone, the helicopter must be brought in at a fast glide and the rotor incidence must then be increased beyond the amount which is correct for steady flight The rotor will then produce an excess thrust and the aircraft will commence to do a normal pull-out Also the speed of the aircraft will fall during the pull-out and the rotor incidence relative to the flight path will have to be continually increased so that for each speed it is always more than the amount which would be correct for steady flight In this way the kinetic energy of forward motion is exchanged for the temporary excess thrust required to perform a pull-out and the result is that, in general, the downward velocity has been eliminated at the expense of forward speed

If we consider a helicopter which is gliding so fast that the arrow tip is resting on B, then if the rotor incidence is increased by a small amount and the aircraft is subsequently allowed to settle down in steady flight, it will do so in a condition indicated by an arrow resting on some such point as A, and the arrow will then be much shorter than before, indicating that a small increase of rotor incidence corresponds to a considerable loss of speed in steady flight and to a much more considerable loss of kinetic energy since the initial speed was high and the kinetic energy is a function of the square of the speed

So long as a small increase in rotor incidence corresponds to a substantial loss of kinetic energy, a pull-out can at least be started, but consider the thick arrow in its present position Here even a large increase in incidence corresponds to only a small change in speed and a negligible change in kinetic energy since the initial speed is low Even if the rotor were suddenly tipped up at right-angles to the flight path all that would happen would be that the arrow would swing down to indicate vertical descent and then it would be too short to reach the curve until the helicopter had settled down to a steady flight in the new condition

To measure the length of the arrow in this diagram it is necessary to swing it on to one or other of the scales If it is swung up to the top scale it can be seen that its length in the position shown corresponds to a glide approach at an indicated airspeed of 25 m p h in the Hoverfly I and it is clear that in these conditions the kinetic energy of forward motion is, for practical purposes, exhausted so that no sort of pull-out is possible from an approach glide at or below this speed In fact, for the Hoverfly I , there is no condition of steady gliding flight corresponding to an airspeed of less than about 23 m p h , although this is not indicated by an ordinary A S I , because the pitot tube is usually horizontal so that it does not register flight path speeds in steep descents

In engine-off landings from approach glides as steep as that indicated by the arrow, the elimination of downward velocity is entirely dependent on the use of the collective pitch control as a means of extracting energy from the rotor to provide the required vertical force, and none of the helicopters in common use today is suitable for landing gently at zero ground speed in still air from an approach glide of this kind

As the speed of the approach glide is increased above the minimum airspeed it again becomes possible to commence a pull-out, but a considerable amount of energy is required to complete this manoeuvre and, in the case of the Hoverfly I , a simple pull-out cannot be completed until the speed of the approach glide has risen to somewhere between 45 and 50 m p h I A S Above this speed the collective pitch control can no longer conveniently be used to assist in arresting downward velocity in an actual landing, and for this reason I will refer to the approach speed at which a simple pull-out is just possible, as the change-over speed

Above the change-over speed a horizontal float becomes possible after the pull-out The minimum speed at the end of an ordinary float occurs when the kinetic energy of the forward motion is exhausted and it is basically the same speed as that represented by the length of the thick arrow There is, however, a difference between conditions in a glide and those in a horizontal float This is illustrated by the small diagrams in the centre of the illustration, which show that whereas in a glide the Total Air Force is vertical and equal to the weight, in a float it is the lift which is vertical and equal to the weight Since the disposition of the forces is otherwise identical it follows that they are slightly bigger in a float for the same rotor incidence and the corresponding speed is approximately 10% higher, so that for the Hoverfly I the minimum speed at the end of an ordinary float is about 28 m p h

The lower half of the illustration merely summarizes part of what we have seen in considering the top half We have already noted that the kinetic energy of forward or linear motion depends on the square of the speed and the lower curve shows how the initial energy of the approach glide increases with speed It also indicates roughly the energy required for the pull-out and the rapid manner in which the energy available for the float increases with the speed of the approach glide

Now, in an emergency the collective pitch control is sometimes used at the commencement of an engine-off landing, but our practice of engine-off landings is still almost entirely based on the azimuth stick as the instrument for eliminating downward velocity Therefore, if we consider only engine-off landings corresponding to engine failure at a sufficient height to allow the pilot full choice of his approach, I think I will not be treading on too many toes if I regard the flare-out as a special kind of pull-out and say that our present practice is based on the motions of pull-out, horizontal float, and final sit-down with the aid of the collective pitch control

In engine-off landings of the kinds usually practised, the float is sometimes absent, and so occasionally is the use of the collective pitch control Also the collective pitch control is sometimes used to cushion the fall of the helicopter after a flare-out some distance above the ground and sometimes merely to hold it in the air while it continues to lose forward speed after the end of a normal float But before we consider these motions in detail I must first clear up a statement which I made earlier and which is repeated in Fig 12, to the effect that the collective pitch control cannot conveniently be used to assist in arresting downward velocity above the change-over speed

At first sight this seems to be rather odd, because the collective pitch control is at all times a powerful means of arresting downward velocity and whereas it is the only means of doing this from glides at the minimum airspeed, its effectiveness is also very considerably increased in forward flight In fact, even if a fully-loaded Hoverfly I is put into a glide at any A S I reading between, say, 35 and 70 m p h, the altimeter hand, which rotates quite fast in a steady glide, can easily be stopped momentarily by pulling up the pitch lever even if the speed is kept constant and the throttle shut At an A S I reading of between 40 and 60 m p h the altimeter hand can not only be stopped but it can be held stationary for a brief period during which the machine is flying horizontally without power at more or less the original forward speed

On the other hand, if an attempt is made to eliminate downward velocity by means of the collective pitch control in a landing from an approach glide at more than the change-over speed, the pilot will find himself in a dilemma, because the only way in which he can reduce his ground speed is by tilting the helicopter backwards If he starts to do this before using the collective pitch control the result will be an ordinary pull-out or flare-out If he pulls back the azimuth stick at the same time as he uses the pitch lever he will find the helicopter doing an excessively hard pull-out, with the result that his last ground speed will be considerably greater than his first and he will have to down pitch and quickly think of some other manoeuvre Finally, if the pitch lever is used first from a glide above the change-over speed, the velocity of the helicopter cannot be subsequently reduced to less than the minimum steady airspeed, so that the forward component of this velocity can be appreciably reduced only at the expense of a heavy landing

We can now examine the kinds of engine-off landing which can be practised with the helicopters at present in common use and in this connection I have in mind particularly the Hoverfly I , which is a very good machine for this kind of practice since it gives the pilot manual control over the collective blade pitch, which I believe to be essential, and it is also so arranged that the main rotor can safely be inclined backwards at quite large angles, even when the tail-wheel is touching the ground (Fig 13 shows this condition) The aircraft is already inclined fairly well backwards and the nose could be raised a good deal further without endangering the tail rotor Also, at this point, I must remark that because a landing is a manoeuvre which is by definition conducted close to the ground and is always seen in relation to the ground, the effect of the wind speed on its appearance causes such confusion in the arguments which usually follow that it is absolutely essential to base our discussion strictly on no-wind conditions

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Fig 13 Engine-off landing attitude of Hoverfly I

The upper part of Fig 14 shows the essential attitudes and motions of an engine-off landing from a high speed approach The speed figures quoted are subject to considerable variation, but they are in fact typical of one kind of landing which has been extensively practiced at Beaulieu, where, in initial tests and in subsequent training and practice, well over 200, and probably by now nearer 300, of these landing have been made without mishap   I think this landing is ideal for initial training purposes because it is divided into a number of separate and distinct movements in which mistakes are easily noticed for correction in subsequent practice   It is useful for any ordinary forced landing in open country and it can also be modified to suit many special circumstances   In this landing the collective pitch control is used only in the " extra float," and the manoeuvre comprises a fairly fast approach glide, a gentle pull-out, and a horizontal float, so that it is very similar to an aeroplane landing   The feature which distinguishes it from other engine-off landing practised by rotating-wing aircraft is the deliberate inclusion of the horizontal float after the completion of the pull-out

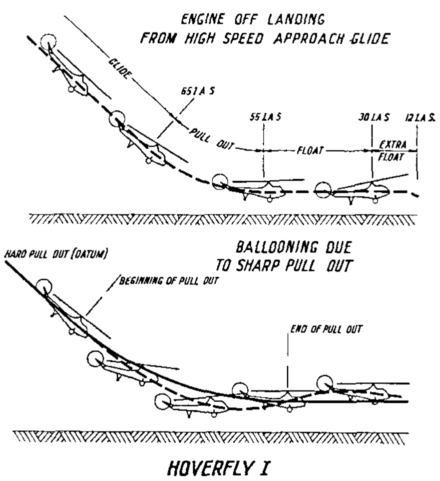


Fig 14   High speed approach glide

The float is typically entered at a fairly high forward speed with the fuselage substantially horizontal, and we have already seen the conditions at this point are governed almost entirely by the speed which the pilot chooses for the approach glide   Thus the conditions of entry into the float are voluntary but so long as the float remains level the subsequent deceleration of the aircraft, and the corresponding adjustment of its attitude, are governed exclusively by its aerodynamic characteristics and are therefore involuntary , with the important exception that the pilot can at any time discontinue the float, either by allowing the aircraft to settle onto the ground or by using the collective pitch control to hold it in the air while it continues to decelerate without further alteration in attitude

The rate at which the rotor incidence, and the attitude of the fuselage, increases during a float, is of particular interest in connection with the landing of helicopters in which a large backward inclination of the fuselage is not permissible near the ground because of the possibility of fouling the tail rotor   The incidence of the rotor varies inversely with the square of the speed, so that the change in rotor incidence for a given reduction in speed is small when the speed is high, but becomes quite large at low speeds   Also the deceleration of the aircraft, as a fraction of G, is simply the inverse of its Lift/Drag ratio, which is the same as the Gliding Angle The Gliding Angle of the Hoverfly I varies from about 1 in 4 at 70 m p h down to 1 in 2 at 30 m p h, so that if it is brought in fast its initial deceleration is about one-fourth of 1G, which is quite small, but the deceleration will increase to approximately a half of 1G at the end of the float and the speed will then drop off rapidly

A simple calculation indicates that a float between the speed indicated in Fig 14 would last little more than 3 seconds, in which time the helicopter would travel about 200 feet, but in a film which I hope to show after the lecture you will see the much longer floats which result from fast approach glides Owing to the improved Lift/Drag ratio at high speeds the speed lost in the pull-out is less from a fast glide than from a slow one, so that if a Hoverfly I is brought in at 75 m p h it will still be doing about 70 m p h when it enters the float, which will then last about six seconds and be about 450 feet long

Six seconds does not sound very long, but you will see from the film that it is much longer than is needed to correct even gross errors in the height of the pull-out Also during most of this time the rotor incidence changes very slowly so that the pilot has no difficulty in judging when the inclination of the fuselage has gone far enough For this reason the risk of fouling the tail rotor on the ground during a horizontal float is negligible for a pilot who is at all familiar with the proper approach speed for his aircraft Even when the speed has fallen as low as 35 m p h at the end of the float the fuselage will still be only slightly inclined backwards, and provided the helicopter has a suitable undercarriage it can quite comfortably either sit down at this speed or use the collective pitch control for an extra float, in which it will continue to slow down without increasing its tail-down attitude The speed lost in this way depends on the energy stored in the rotors and on the backward inclination of the rotor, but with our present helicopters it would amount to about 15-20 m p h

The extra float can, of course, only be maintained for a brief period because it results from progressive slowing down of the rotor and corresponding increases of collective pitch, neither of which can be continued indefinitely Nevertheless, the high deceleration at low speeds makes the extra float well worth while and a practiced pilot can regularly use this brief period to knock the forward air speed of a Hoverfly I down from about 30 m p h to little more than a walking pace, although 12 m p h would be a more usual figure in training

So long as the approach glide is fast the attitudes and motions of the helicopter remain as shown in the top part of Fig 14, where the extra float is voluntary and the length of the ordinary float can be varied at will by altering the speed of the approach glide But when the speed of the approach glide is reduced below about 65 m p h, in the case of the Hoverfly I, the character of the landing begins to alter and we find that as the ordinary float disappears the extra float becomes a necessity for correcting errors in the height of the pull-out Also the rapid changes in fuselage attitude, which before occurred only at the extreme end of the float, now begin to appear at the end of the pull-out and the nature of the pull-out itself begins to be affected to an increasing degree by the inertia characteristics of the rotor, which give rise to a surging or flaring of the rotor speed, so that we will have to examine this phenomenon before considering the performance of landings from low speed approaches

Fortunately we can understand the flaring of rotors without becoming involved in lengthy arguments about autorotation, for it is a well-known characteristic of a rotor which is auto-rotating at constant pitch that it has a particular speed of rotation when carrying a particular load and this rotor speed is substantially independent of the forward speed of the aircraft Also, if the load on the rotor is increased, as in a steep turn, the rotor speed will increase and, similarly, when the extra load is removed the rotor speed will fall again to its original value

But we have already noticed that, at a given forward speed of the aircraft, there is a particular amount of lift which may be expected from the rotor when it is at a particular angle of incidence under steady conditions Also, except at very large angles, when the angle of incidence is increased the lift of the rotor will increase, so that if the aircraft happens to be doing a fast glide approach when the pilot increases the rotor incidence the resulting increase in lift will cause the aircraft to start doing a pull-out

So long as the approach glide is fast and the rotor incidence increased gently the resulting pull-out resembles that of an aeroplane sufficiently closely to require no special comment, but if a sharp pull-out is attempted the picture immediately changes and the lower part of Fig 14 is an attempt to illustrate what happens

In a sharp pull-out the incidence of the rotor is rapidly increased to a large value, which would correspond to a high lift in steady conditions But, if we suppose the rotor incidence to be instantaneously increased, it is obvious that the rotor speed could not increase in a similarly instantaneous manner, although it might grow very rapidly, and the expected large increase in lift does not fully develop until the rotor speed has achieved an appropriately high value Therefore, at the beginning of a sharp pull-out, the aircraft, in spite of its tail-down attitude, has a tendency to continue its original flight path while the rotor accelerates This tendency can be seen by comparing the dotted flight path with the continuous line which represents the pull-out which would be done by a helicopter in which the collective pitch control is used to prevent the rotor from accelerating and thus absorbing energy

When the rotor speed has flared up to something like the value appropriate to the expected increase in lift, the resulting pull-out may be very sharp indeed, but when the downward velocity is eliminated the pilot will immediately want to reduce the rotor incidence in order to enter smoothly into the float By this time, however, the rotor will have achieved a high rate of rotation and until it has slowed down again it will continue to deliver an excessive thrust, so that in practice it is almost impossible for the pilot to prevent the aircraft from ballooning

The lower part of Fig 14 shows the typical motion of a helicopter when a sharp pull-out is done from a high speed approach (Note This illustration is over-simplified because the fuselage is drawn parallel to the rotor in each case For instance in the last figure but one the rotor would be roughly level as shown, but the fuselage would still be in a slightly tail-down attitude, indicating a very forward position of the azimuth stick) In these circumstances the ballooning is of no consequence, because the float gives ample time for the aircraft to settle down The aircraft can also come surprisingly close to the ground even when the pull-out is commenced at an apparently reasonable height, but this again is hardly likely to be dangerous because the tail is fairly well up even at the bottom of the pull-out   Nevertheless it is not a pretty manoeuvre at high speed

So long as the pull-out is gentle the tendency for the rotor to flare is a function of the speed of the approach glide   If the glide is fast the rotor is at a very small incidence so that its thrust is nearly perpendicular to the flight path and very nearly equal to the lift   The small increase in lift required for the pull-out is then produced by correspondingly small increases in the thrust and speed of the rotor   But at low speeds the rotor thrust is inclined backwards at a large angle relative to the flight path so that a small increase in the lift, which is perpendicular to the flight path, can only be produced by a large increase in rotor thrust, which is accompanied by a correspondingly large increase in the speed of the rotor   On the other hand, in a very slow glide near the minimum steady airspeed, the rotor incidence is already so large that to increase it further produces only negligible increases in rotor thrust and speed   Hence there is an intermediate range of approach speeds for which the tendency for the rotor to flare is a maximum

The upper useful limit of this range occurs slightly above the change-over speed, say 50 m p h , for the Hoverfly I   The ordinary float is then negligible and the rotor revs at the beginning of the extra float, though past their peak, are still high enough for the forward speed to be easily reduced to practically zero   At higher approach speeds the surplus rotor revs obtained in the flare are damped out before the extra float is commenced

The pull-out from a glide at the change-over speed should end up with the aircraft at the attitude and speed, say 30 m p h , appropriate to the end of a float and with its rotor revs flared up to their peak value   If a pull-out of this kind is found to be too low it can be tightened with the collective pitch control without altering the attitude of the fuselage, but in general it would be aimed to finish slightly high to allow a reasonable margin for error, so that the extra float which immediately follows would be slanting downwards

In pull-outs below the change-over speed level flight can be achieved but at much lower forward speed so that practically no energy is supplied to the rotor in the last part of the manoeuvre   A feature of these pull-outs is, therefore, that the peak rotor revs occur before the end of the pull-out and are largely dissipated by the time it is completed   The classic example of this is the flare-out shown in Fig 15, in which the motion of the aircraft is, ideally at any rate, completely arrested at the end of the manoeuvre, because the rotor, having achieved its peak revs , continues to develop sufficient excess thrust for height to be maintained while the remaining forward speed is eliminated   During this brief period the rotor is required to produce a large thrust at substantially zero speed so that it decelerates very rapidly   There are a number of interesting considerations relating to the flare-out, but when it is considered as part of the engine-off landing manoeuvre of a helicopter with a tail rotor, the most obvious is that because of the excessive inclination of the fuselage the flare-out must be done well clear of the ground, so that when it is completed the helicopter still has to be lowered vertically onto the ground   As the kinetic energy of the rotor is then largely exhausted it is difficult to do this gently and the practice flare-outs with our present helicopters which I have so far seen have been done about 15-20 feet above the ground so that the pilots have naturally cheated by using the engine for the touch-down

There is quite a sizeable family of rotating wing aircraft, typified by the C 30 Autogiro, which do not provide the pilot with control over the collective pitch of the blades, and the proper object of the flare-out is to provide this sort of aircraft with the only means by which motion can be arrested without varying the collective pitch An aircraft which is properly designed to do flare-out landings is usually of low disc loading and has no tail rotor so that the whole manoeuvre can be performed slowly and close to the ground In these circumstances the flare-out is a simple and elegant form of landing, although even in the case of the C 30 a forward air speed of 10 m p h is more usual than zero speed at touch-down

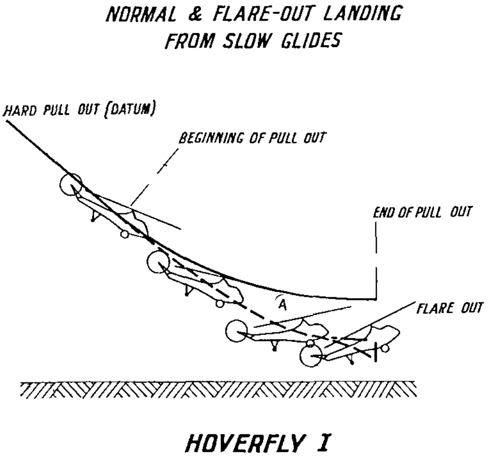


Fig 15 Slow approach glide

A feature of a flare-out in which the speed is substantially eliminated without ballooning is that the last part of the manoeuvre is roughly level In Fig 15 I think the curvature of the flight path is shown in a reasonably correct manner and it will be noticed that the greatest curvature, and therefore the peak rotor thrust and speed, occurs at the position occupied by the figure A, where the fuselage attitude is still reasonable Also the position of the point A is not very critical, as far as the rotor revs are concerned, because, although these fall off rapidly after reaching their peak, they are built up fairly steadily, as indicated by the slowly increasing curvature of the initial part of the pull-out Therefore, if the fuselage inclination is not allowed to increase beyond the desirable landing attitude, the pull-out will finish at A and the slanting extra float can be commenced immediately while the rotor revs are at roughly their peak value

In the Hoverfly I, landings of this kind can be done from glide speeds as low as 40 m p h, and if the conditions at the point A are compared with those at the end of a float they will be found to be much the same So long as the flight path is curved upwards the rotor thrust and revs will be greater than at the end of a float, but this excess thrust will temporarily remain after the flight path curves downwards and will largely compensate for the remaining downward velocity, which is, in any case, not more than 10 ft /sec, or about 7 m p h, even if only half the original downward velocity is eliminated The forward speed is approximately the same as at the end of an ordinary float and so is the fuselage attitude

The slanting extra float is therefore much the same as in landings from higher approach speeds. In short, this has the appearance of an easy landing and this was also the opinion of Lt. HOSEGOOD, who did the only one of which I have any direct experience. I have been a passenger in many engine-off landings, including a number, with S/Ldr. CABLE, from approach glides at 50 m.p.h. in the Hoverfly I, but this is certainly the easiest I have seen yet as well as the most efficient for setting the helicopter down exactly where it is wanted. I believe this landing is often demonstrated by the Bell 47, also Mr. HAFNER'S A.R. 111 Gyroplane had a collective pitch control and, although I never saw it fly, I think this must be the kind of landing which that remarkable machine was doing before the war.

In future helicopters, the kinetic energy stored in the rotors will be about twice what it is today and an engine-off landing of this kind at zero ground speed will be so simple that I hope it will become the normal landing of a helicopter except in very special circumstances.

We have now completed our examination of the engine-off landings which can be practised with the helicopters now in common use and I turn back to Fig. 12 as a convenient starting point for a discussion of the landings which will be typical of the future. So far we have considered the speed of the approach glide to be varied from 75 m.p.h. I.A.S. down to 40 m.p.h. I.A.S., and in all these landings the use of the collective pitch control has been of secondary importance, being voluntary when the approach glide is fast and assisted by flaring of the rotor when the approach glide is slow.

Landing from fast glides will become increasingly easy with continued improvement in top speeds and gliding angles, but these improvements are likely to be significant while the helicopter is looking for a landing place rather than in the actual landing, because the best gliding performance will always be associated with comparatively low rotor speed. The distinguishing feature of the approach glide of future helicopters will be that the rotor speed will be high by present standards, while the corresponding glide performance remains much the same as it is now. When a landing place is decided on the action of increasing the rotor speed in preparation for the landing will be in some respects analogous to putting down the flaps on an aeroplane. Once this action has been taken the easiest landing is done from a glide at about 30-40 m.p.h., and in future the fast approach glide will be seen only as part of a training exercise designed to separate the motions of a landing for the purpose of initial instruction.

Our present helicopters are already capable of reasonably easy engine-off landings from approach glides as slow as 40 m.p.h., and the problem of future engine-off landings is concerned with the ability of a helicopter to land from steep glides at the minimum steady airspeed. Here the collective pitch control is the only means of effecting a gentle landing and the typical motion of the helicopter during the landing may be described as a pull-up. Also the typical application of the pull-up is for arresting the downward motion of a helicopter which is descending vertically in still air at its terminal velocity.

In these conditions the sinking speed of a C.30 Autogiro would be about 35 ft./secs., of a Hoverfly I., about 40 ft./secs., and of a contemporary design with high rotor speed, about 45 ft./sec., or about 30 m.p.h. vertically downwards, and not so long ago it was quite commonly thought impossible to design a practical helicopter which would be capable of using the kinetic energy of its rotors to arrest this motion so that a gentle engine-off landing could be made in pure vertical flight

As you can imagine, my experience with the Focke gave me a rather personal interest in this problem, and, having opened my mouth rather wide on the subject, I thought it might be as well to find some logical basis for supposing that vertical engine-off landings are not only desirable but also possible and even probable At first this seemed rather a formidable undertaking and I got some quite severe headaches from trying to turn inside-out Dr BENNETT's well-known calculations on the jump take-off of Autogiros O'HARA, of Beaulieu, has succeeded in doing this, but fortunately I found that the performance of a helicopter in a pull-up can also be examined in a very simple manner, provided attention is confined to particular cases rather than general solutions, and it was quite easy to show that a gentle engine-off landing in pure vertical flight is possible with a helicopter having characteristics which are within the normal range of current design practice

So far as I know these first estimates are still the only published information on this subject They are based on two very conservative assumptions, but all estimates of this kind are to some extent guesswork and it is convenient to examine the more pessimistic guesses first On the other hand, although I think there is no doubt about the possibility of such landings, the ease with which they can be performed remains a matter of opinion For this reason I will briefly outline the way in which the estimates were made

If, for a given helicopter, we know the inertia and profile drag characteristics of the rotor system, and the initial rotor speed and rate of descent, we can find out the rate at which the kinetic energy of the rotor system is being expended at any instant during a pull-up, provided we know the manner in which the rate of descent and the flow through the rotor have varied up till that instant

The reason why the flow through the rotor is important is easily seen if we consider a helicopter being lowered steadily through the air with its rotor blades outstretched but not revolving In this case the air will pass freely up through the rotor because there is nothing to stop it But if the blades are allowed to rotate so that in steady flight they produce a thrust equal to the weight, it is clear that they can only produce this thrust by throwing air downwards or, in other words, by beating down the air which is trying to leak up through the rotor

While the helicopter is descending it is continuously losing the potential energy, or capacity for doing work, which it possesses by virtue of its height above the ground, and this energy is being lost because it is being expended by the rotor in throwing air downwards (relative to the ground)

Now, if there were no other losses in the system, the potential energy supplied would be equal to the energy required by the rotor to induce the required downward flow of air Also the downward velocity of this induced flow would be exactly equal to the rate of descent, that is, exactly equal to the speed at which air is trying to leak upwards through the rotor In consequence, there would be no flow at all through an ideal rotor which is rotating freely in steady vertical descent

Thus any flow through a descending rotor is a measure of the energy which is being absorbed or given out by the rotor itself as distinct from the potential energy which is being lost by the aircraft as a whole For instance, a certain amount of energy is absorbed by a real rotor in overcoming the profile drag of the rotating blades and therefore in steady vertical descent potential energy must be supplied at a greater rate than is needed to produce the required induced flow Thus the steady rate of descent of a real helicopter is greater than the downward velocity of the induced flow so that air leaks upward through the rotor at a small velocity

Again, in the particular case of hovering flight without engine power, we know, for instance, that the whole of the downwash through the rotor is created by energy extracted from the rotor Also for any rotor speed we can calculate the rate at which additional energy is being extracted to overcome the profile drag of the blades (The information required to do this is obtained from standard curves such as those shown in Fig 16, which refer to the blades of the Hoverfly I and of a helicopter of contemporary design)

Therefore, if we know the inertia characteristics of the rotor system, we can find the rate at which it is decelerating at any rotor speed But we have already seen, in the case of an ordinary float, that when deceleration is known as a function of speed a very simple calculation will tell us how long it takes for the speed to fall from its initial value to the minimum permissible Thus we can easily calculate how long a helicopter can remain in hovering flight, or any other steady condition, after the engine has failed

In a very similar way we can estimate the extent to which the rate of descent of a helicopter can be reduced in a pull-up without engine power The calculation is still very simple, but in a pull-up the rotor thrust, the rate of descent, and the flow through the rotor are all varying, so that before an estimate can be made it is necessary to state the kind of landing which is to be considered For academic reasons it might be convenient to consider a landing in which the coning angle is constant or one in which the rotor thrust varies in a particular manner with rate of descent But in a real pull-up the rotor thrust ought to be under the control of the pilot and I think a practical case is fairly well represented by the motion of a helicopter doing a pull-up at constant thrust, which corresponds to applying a constant pressure to the brake pedal of a car To get a comprehensive picture it is then only necessary to compare the performance of the helicopter in a number of pull-ups at different amounts of constant thrust

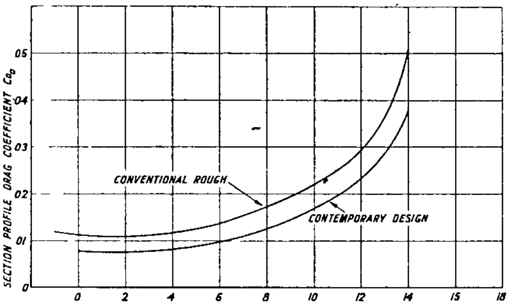
The assumption of constant rotor thrust means that the pull-up is done at constant deceleration and the rate of descent is then known at any instant Also, if the thrust and rate of descent are known at any instant, we can find the corresponding flow through the rotor from Fig 17, which, so far as we are concerned, shows the relation between the rate of descent of a helicopter (plotted here as $\frac{1}{f}$) and the flow through the rotor (plotted here as $\frac{1}{F}$) when the thrust is constant This curve is in three parts, which are labelled to show to what condition of flight they refer It is not a calculated curve, because there is no reliable means of calculating it Instead, it is an estimate based on model tests and on a few tests of full scale rotors The precise shape of the curve remains to be determined and is probably also a function of disc loading Perhaps the best thing I can say about this particular curve is that, apart from fitting a few test results, it is cribbed from the best possible authorities, so I don't think it will be suggested that the probable inaccuracies in its shape would seriously affect conclusions with regard to pull-ups

In steady vertical descent we can calculate the upward flow through the rotor which provides the energy required to overcome the profile drag of the blades, so that we know $\frac{1}{F}$ which is small, and we find that the operating state of the rotor is then defined by a point near the lower end of the top branch of the curve From the vertical scale we have the corresponding value of $\frac{1}{f}$ from which the rate of descent can be calculated Similarly, if we know the rate of descent we can use the curve to find the corresponding flow through the rotor

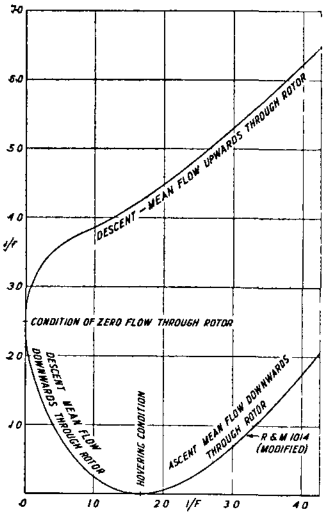
In a pull-up at constant thrust we know the thrust and the rate of descent at any instant, and if we assume that the curve applies to unsteady as well as to steady motions, we can find the corresponding flow through the rotor If the pull-up is performed at all rapidly this assumption is grossly conservative, as we will see later, but even so the resulting estimates are quite encouraging

When all the necessary information is collected together it can be fed into a very simple equation which shows the manner in which rotor speed falls off with time after the commencement of a pull-up The results are shown in Fig 18 for a typical contemporary design in five pull-ups at

Fig 16

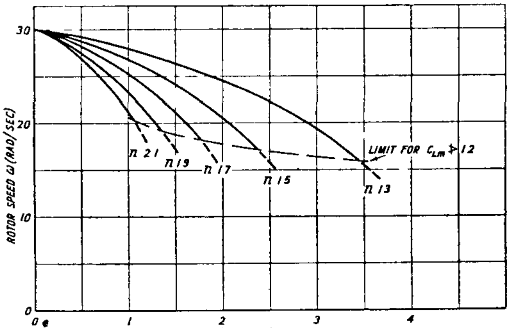


ASSUMED VARIATION OF PROFILE DRAG COEFFICIENT FOR TYPICAL HELICOPTER BLADE AEROFOIL SECTIONS



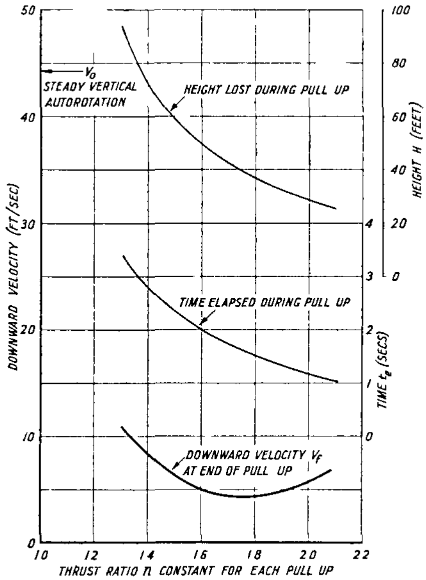
ASSUMED RELATION BETWEEN COEFFICIENTS 1/f & 1/F FOR FULL SCALE ROTORS

Fig 17



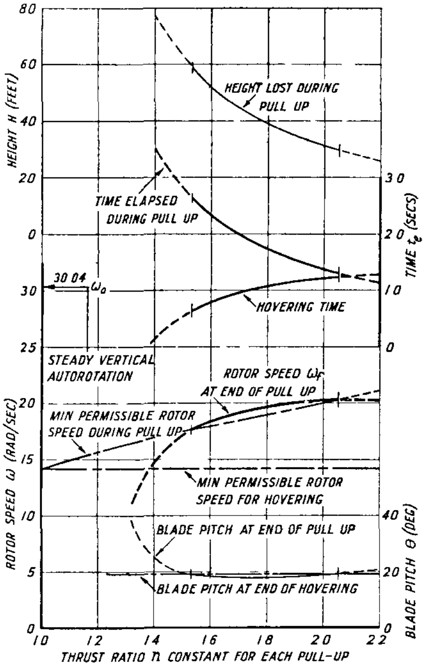
HELICOPTER A VARIATION OF ROTOR SPEED DURING PULL-UPS

Fig 18



HELICOPTER A PERFORMANCE IN VERTICAL PULL-UPS WITHOUT ENGINE POWER

Fig 19



HELICOPTER C PERFORMANCE IN VERTICAL LANDINGS WITHOUT ENGINE POWER

Fig 20

different amounts of constant thrust The thrust is expressed here as the ratio *n*, so that the right hand curve refers to a pull-up in which the rotor thrust is 1 3 times the weight, and the left hand curve refers to a pull-up when the thrusr is 2 1 times the weight The horizontal scale is seconds, but the vertical scale is in radians per second, so that the rotor speed in r p m would be slightly less than ten times the figures shown The initial tip speed of this rotor is about 705 ft /sec , or 0 64 times the speed of sound

As the rotor speed falls off while the thrust remains constant the blades would ultimately either stall or cone up until they reached their upper stops In this design they would stall first, and each curve is continued to a point where the mean lift coefficient of the rotor blades has risen to 1 2, which is taken to indicate stalling and therefore the end of the pull-up The time spent in the pull-up is therefore known in each case, so that the rate of descent at the end of the pull-up is easily calculated The way in which the rate of descent at the end of the pull-up varies with the thrust during the pull-up is shown in the lower curve of Fig 19

The other curves in this diagram show the way in which the height lost in the pull-up and the time spent in it, very with the rotor thrust According to this diagram the pull-up can be commenced at any height between 100 ft and 20 ft without the final velocity exceeding 12 ft /sec , which is the capacity of a normal undercarriage, while the final velocity would be less than 6 ft/sec if the pull-up is commenced between 60 ft and 30 ft from the ground

As an example of pessimism I think you will agree that this is not a bad effort Nevertheless, the curves do not indicate that the helicopter would stop and as I was reluctant to abandon the conservative basis of these estimates it was necessary to find some means of representing the degree of improvement which could be expected without major alterations in the design If such an improvement were needed in an actual case it would be obtained by small decreases in disc loading and solidity and by small increases in rotor speed and blade weight, but to preserve a direct comparison in the estimates I lumped these all together and represented them by a single increase of 30% in the weight of the main rotor blades, which amounts to a 2% increase in the total weight of the aircraft As this particular design can hover in still air at much more than its normal weight, I don't think even this unnecessarily large increase of 2% would noticeably affect the normal performance The effect on the performance in a vertical pull-up is, however, quite impressive, as shown in Fig 20

The thick curve in the middle of the diagram shows the way in which the rotor speed at the end of the pull-up varies with different values of the thrust The slanting chain-dotted line just below the thick curve indicates the way in which the minimum rotor speed, at which blade stalling occurs, increases when thrust is increased Comparing this slanting line with the thick curve we find that the rotor speed at the end of the pull-up exceeds the minimum permissible over quite a large range of variations in thrust Within this range the helicopter will be brought to rest in a pull-up without stalling of the blades and the rotor speed at the end of the pull-up is then still a good deal higher than the minimum which is permissible in hovering flight, so that a brief period of hovering flight will be possible before the helicopter settles onto the ground The time elapsed during the pull-up and the time available for hovering are indicated by the curves immediately above the thick curve

Here again the performance is under-estimated because the hovering time refers to hovering in free air and makes no allowance for the ground cushion Also, a closer inspection of the thick curve shows quite clearly that the assumption of constant thrust does not represent the most effective pull-up because if we consider the right hand end of the thick curve where it crosses the slanting line it is obvious that although the pull-up cannot be continued at the same high thrust it could quite well be continued at a lower thrust, in which case the helicopter would have started to go up again before blade stalling occurred

In a typical landing in which the pull-up is done at constant thrust, the motion of the pitch lever would be as shown in Fig 21, where the sharp increase in pitch at the beginning of the pull-up corresponds to the sudden increase of thrust to the value which is afterwards held constant

(The figures in this diagram are calculated in a rather crude way and are intended to indicate motion of the pitch lever rather than absolute values of blade pitch, which is shown too small by about a degree)

The sudden decrease of pitch at the end of the pull-up would then be necessary to prevent the helicopter from rising again On the other hand we have already noted that the thrust in a pull-up ought to be high at the beginning and low at the end, so that in the most effective pull-up the initial sharp increase in pitch would be even more marked than in Fig 21, while there ought to be a less marked reduction in pitch at the end of the pull-up In fact, this diagram suggests that the most efficient pull-up is one in which the pitch is suddenly increased by about 10 degrees and then left alone until it is wanted for final adjustments as the helicopter settles onto the ground This action of the pitch lever could, of course, be obtained automatically by pressing a button, but I do not think automatic devices of that kind should be encouraged in piloted aircraft

Now, if the pull-up has been performed in the most effective manner the original helicopter could have stopped quite easily without the blade weight being increased at all, and at this point I was prepared to let the matter rest for the time being because it was already clear that engine-off landings in pure vertical flight are possible within the range of our current design practice But I did mention that not only had the ground effect been neglected in hovering, but also the inertia of the air had been neglected during the pull-up, and this latter feature of the estimates had since been the subject of quite severe criticism on the grounds that they are too pessimistic

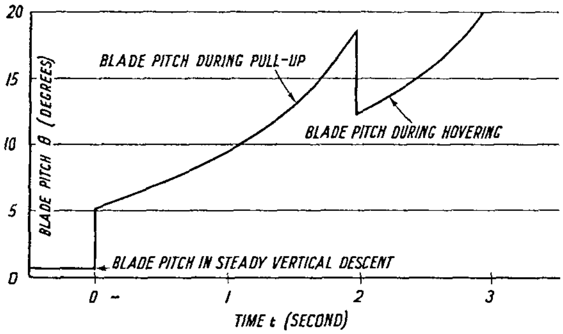


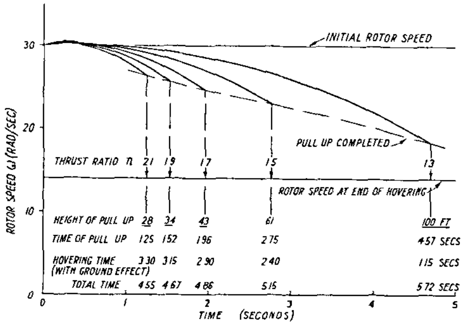
Fig 21

HELICOPTER C MOTION OF PITCH CONTROL IN A VERTICAL LANDING WHEN n=17 IN PULL-UP

Now the assumption of constant rotor thrust during the pull-up implies that at the beginning of the pull-up the thrust is instantaneously increased to *n* times the weight of the aircraft and the reason why these estimates are pessimistic is that to use the curve of Fig 17 in the way it was used is equivalent to saying that the velocity of the downward induced flow is also increased instantaneously to *n* times its normal value But the induced flow is not something which happens only in the plane of the rotor—on the contrary, to speed it up entails altering the whole flow pattern around the rotor and the inertia of the air involved in this flow pattern is considerable, so that an appreciable time is required to establish a change in the induced velocity

I do not know of any reliable method of estimating this time, but certainly in a pull-up the induced velocity would not increase to the value appropriate to the vortex ring state through which the helicopter is assumed to pass in the estimates we have considered Also, if the pull-up is quick, it would in practice be performed close to the ground, which would further interfere with the build-up of induced velocity and in these circumstances I think it is not unreasonable to suppose that the increase in induced velocity is small

If this is so, the effect on the performance of the pull-up is very considerable, as shown in Fig 22, which illustrates the performance of the original helicopter with light blades, assuming the induced velocity remains throughout the pull-up at the value appropriate to steady vertical descent Now this diagram and the previous estimate for this helicopter represent two extreme possibilities and the truth lies somewhere between them For instance, an unaltered induced velocity cannot reasonably be accepted in the case of the right hand curve, which represents a pull-up started at 100 ft and lasting over 4½ seconds, and in this case the previous estimate of a final velocity of 12 ft /sec is probably somewhat nearer the truth On the other hand it is very unlikely that anyone would start a pull-up at 100 ft , and when we consider the more usual height of 40-50 ft it is clear that the pull-up would be over in approximately two seconds and would take place largely within the ground cushion In these circumstances there will probably not be any large build-up of the induced flow and I believe the figures quoted in this diagram are close to the truth for typical pull-ups at constant thrust in actual future landings



HELICOPTER A INDUCED VELOCITY UNALTERED BY PULL UP

Fig 22

But we have already noticed that the rotor thrust should be high at the beginning of a pull-up and low at the end for maximum effectiveness and this is very clearly indicated in Fig 22, which shows that in the first half-second of a pull-up the pilot has at his command a brake of almost unlimited power, within the range which he is likely to require, which costs practically nothing in rotor energy The slight flaring of the rotor when the pitch is increased is a phenomenon which must occur whenever the thrust of an auto-rotating rotor is suddenly increased without a correspondingly sudden increase in the induced flow The phenomenon is very short-lived in vertical flight because it can only occur while air is flowing upward through the rotor, whereas the extra thrust very quickly reduces the rate of descent to less than the velocity of the induced flow, after which the flow through the rotor is downward In practice the phenomenon would not produce any significant increase in rotor speed, but it would be noticeable as a small time-lag between the extra thrust and the falling-off of rotor speed

When allowance is made for the inertia of the induced flow the corresponding estimate of the motion of the pitch lever during the landing will also be altered and the initial sharp increase in pitch shown in a previous diagram would correspond to a much larger increase in thrust so that the collective pitch control may be expected to be more sensitive and more powerful than was originally estimated

The speeds and decelerations shown in this diagram for a typical pull-up from, say 50 ft , are practically the same as in the extra float at the end of an ordinary engine-off landing, namely, an initial speed of 30 m p h and a mean deceleration of slightly more than half of 1G Considering the extra braking power which is available if required, and the allowance of, say, 2 seconds of hovering time for correction of mistakes, it does not appear that a landing of this kind would be very difficult, unless it can be shown that judgment of height and speed in vertical flight is fundamentally different from that in horizontal motion Personally I don't think there will be any difficulty of this kind and I believe that if a pilot approaches the vertical landing gradually in the course of his training he will find it comparatively easy

The vertical landing is certain to be an important feature of a pilot's training because it is typical of all landings from glides at the minimum airspeed In the event of engine failure over built-up areas, or over wooded or uneven ground, a glide at the minimum airspeed is attractive because it allows the pilot to steepen his glide path immediately he sees a clear space for landing, without waiting for the completion of the pull-up which would intervene at higher speeds Also, when descending steeply, he has complete freedom to use the azimuth stick in changing his flight direction without incurring changes in the flight path speed which would upset his judgment Where the helicopter must be accurately positioned for a pull-up in a confined space this freedom and directness in the approach will be valuable features of a helicopter which is capable of vertical engine-off landing

The normal engine-off landing of such a helicopter would naturally be done in the easiest circumstances and these will correspond to a glide speed of 30 to 40 m p h , where the landing will include a little pull-out, a little flare-out, and plenty of pull-up, all combined in a manoeuvre which will be so easy and will take such a long time anyway that the power of the engine could not very well be used even if it was still available When we have got to this stage we will be able to return to the practice of the pre-war flying clubs, where we were taught that every landing should be done as though it were a forced landing in normally easy circumstances I think this is a very wise teaching and I hope that in the course of the next few years the use of engine power will largely disappear from the normal landing of a helicopter

WESTLAND-SIKORSKY S-51

To conclude my talk I have brought with me some slides illustrating the activities of the Westland Co's S-51 helicopter in the demonstrations which it has been giving this summer in all parts of the country The S-51 is a magnificent aircraft with a long history behind it and a great future in front of it As you know, our job at Westlands is to produce a British version and we have made good progress with the work of translating the present American aircraft into British materials, with the Alvis Leonides

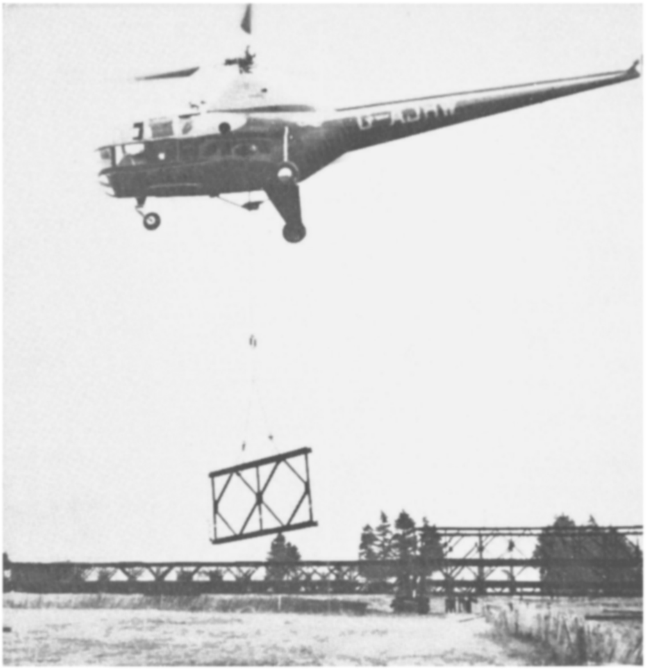


Fig 23 Westland's S-51 lifting a Bailey bridge panel

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as an alternative to the Wasp Junior engine The extensive detail revision of the American drawings to meet British design requirements and to accommodate British proprietary parts, and the considerable work entailed in preparing for production, are being pushed ahead at Westlands with all possible speed by a growing team of able and enthusiastic engineers, with every intention of consolidating the great advantage which we have from our close connection with the Sikorsky Division of United Aircraft

The slides show typical items from demonstrations —

1 Use of Air/Sea rescue hoist

2 Parking between cars

3 Taking man from buoy

4 One item of our normal demonstration included lifting a dummy girder, and this apparently tickled the fancy of Sir Donald Bailey, of Bailey Bridge fame, who invited us to give a demonstration at the Military Engineering Experimental Establishment at Christchurch For this occasion we fitted the machine with a special weight-lifting beam and here you see it lifting —

(i) A section of a Bailey Bridge weighing 600 lbs (Fig 23)

(ii) An engine and mounting weighing 960 lb

(iii) At another demonstration we arrived with the special beam in place and, on looking round for something to lift, we found a crate containing a Gipsy Six engine, which is being lowered on to a very small trolley

These illustrations show the aircraft operating in practically still air without any benefit from the ground cushion, and you will remember from Mr SIKORSKY's lecture that the weights mentioned are far less than the eighteen people which can be lifted in a normal take-off or with the help of a little wind Nevertheless they represent a very useful practical performance, for instance, in carrying food to isolated places

5 In the course of our demonstrations we gained valuable experience in operating in and out of the major London Airports and in flights over the Metropolitan area These flights included many landings at Barnes, and others in Regents Park, on the Horse Guards Parade, etc Here you see the S-51 after landing on the roof of a strong room in the bombed area behind the B B C and immediately outside this lecture hall

Owing to a fit of absent-mindedness on my part my final Slide is missing It was an attractive photograph showing two S-51's leaving Yeovil for our original demonstration at Barnes, but anyway that is a sight which I hope will shortly be a commonplace at helicopter airports all over the country In the meantime much remains to be done and it would be foolish to indulge in unnecessary prophecy, but we hope that by this time next year Westland-Sikorsky S-51's will already be in commercial operation

In conclusion I take this opportunity of thanking the Ministry of Supply for permission to use the material for the first part of this talk and particularly for the assistance I have received from RDL2 and the A F E E Similarly I am indebted to the Westland Company for permission to discuss the S-51 and for their assistance in the preparation of notes and slides

Finally I would like to say that I very much appreciate the privilege and pleasure of this opportunity to address the Helicopter Association and I thank you very sincerely for your kind attention

NOTE—Illustration of the full range of slides shewn has not been possible owing to lack of space—ED

FILM SHOWN ILLUSTRATING MR FITZWILLIAM'S LECTURE

This film was taken at Beaulieu in the summer of 1945 and it shows seven engine-off landings by a Hoverfly I from approach glides at a speed of rather more than 75 m p h A S I It is interesting because it not only shows the long float which results from a high speed approach but also the pull-outs in the first three landings were done very sharply owing to a misunderstanding between the pilot, Lt HOSEGOOD, and myself

These landings followed the original experiments which were flown by S/Ldr CABLE, and they were part of a series in which the length of the extra float was varied from zero to the maximum by varying the amount of collective pitch used The extra float could have been a good deal more effective than it was in these tests because you will notice that the tail-down attitude of the aircraft could quite safely have been considerably increased Also in a real forced landing the engine would be dead and the pitch control could be used to its full extent In these landings, although the engine is not used, it is still idling, and the pitch and throttle synchronising gear of the Hoverfly I is rather awkwardly arranged so that even when the twist-grip throttle is shut as far as possible the engine cannot be prevented from interfering with the landing if the pitch is increased beyond about 10°

(Note —Several members seem to have deduced, from the stroboscopic effects in the film, that the engine was employed in these landings This is definitely not the case, as could be demonstrated by reference to the increasing coning angle in the " extra float ") In these landings the air speed at touch-down is about 12 m p h or less, but you will notice a peculiarity of the Hoverfly I which results in the forward speed increasing on the ground if the rotor is allowed to tilt forward after landing Because of this the aircraft will continue to run along the ground for a surprising distance unless the azimuth stick is held hard back

This motion can, of course, be arrested immediately by use of the brakes, and you will notice that we fitted small bumper wheels on either side to guard against the nose being rubbed on the ground With these in place the aircraft was landed on the runway at speeds up to 25 m p h and on grass at about 12 m p h , but in spite of the rearward position of the main wheels, and the fact that the bumper wheels projected noticeably below the nose, they only contacted the ground twice and on both occasions this was because the main wheel brakes had been left hard on by mistake

Mr Pullin's Vote of Thanks to Mr Fitzwilliams

Ladies and Gentlemen,—It gives me great pleasure to propose a hearty vote of thanks for the excellent lecture so well prepared and delivered by Mr Fitzwilliams

Mr Fitzwilliams commenced his career in rotating wing aircraft when he was transferred from the Turbine Department of Messrs G & J Weir, Ltd , to the Aircraft Section in 1939, which was under my supervision He was so determined to get into the rotating wing field that he really organised own transfer and judging by the progress he has made in the art it will be appreciated that you cannot keep a good man down This is especially true with Mr Fitzwilliams, and he also takes part in the airborne experiments

As I understand the time at our disposal this afternoon has practically expired, I should like you to join me now in a very hearty vote of thanks to Mr Fitzwilliams for the excellent lecture we have so much enjoyed