Convertible Aircraft

By CAPT. R. N. LIPTROT, C.B.E., B.A.

A paper presented to the Helicopter Association of Great Britain on Saturday, 17th March, 1951, at The Royal Aeronautical Society, 4 Hamilton Place, London, W.1.

In the Chair :
N. J. G. HILL, A.M.I.MECH.E., A.R.AE.S.

INTRODUCTION BY THE CHAIRMAN.

THE CHAIRMAN : This afternoon I take the Chair with great pleasure for the occasion is marked by the presence of our friend, Major G. P. BULMAN, President of the Royal Aeronautical Society, and also other members of the Society, who have come along to hear Captain LIPTROT. I know that you will support me in extending to Major BULMAN a very warm welcome. It is the second occasion on which we have been able to meet on common ground, and I know that we shall enjoy listening to Captain LIPTROT on this particular subject.

We have been told that certain of our lectures in the past have been far too technical and above the understanding of some of the more youthful of our membership, and I must say that sometimes even I have viewed with apprehension the mass of mathematical formulae presented by some of our more advanced lecturers, but today I am heartened because our old friend Captain LIPTROT is the lecturer and he is one of those who, although accomplished technically, is able to present his subject in an exciting and yet easily understandable manner, having a style which brings the subject well within my own comprehension.

There is scarcely any need for me to introduce him because he has been known as a strong protagonist and adherent to rotary wings for very many years. Perhaps he will tell us exactly how long one of these days, but we judge from some of his earlier lectures that he was associated with rotary wings in the very earliest stages.

This Helicopter Association is well known for its belief in the future, and I think we can safely say that we are a very forward-looking Association or body. The view we take today may seem to some of us to be just about as far ahead as the helicopter seemed a matter of twenty ot twenty-five years ago, but recent events in America would seem to show that the Convertaplane is not so very far away, and with your permission I would like to review briefly some of the information which we have had from America which indicates the interest which the United States Air Force and Navy have taken in this Convertaplane idea.

In 1950 a special study was made to determine the general characteristics of the Convertaplane, sponsored by the United States Air Force. Later on specifications were delivered to the American aircraft industry, and today no less than seventeen different firms have submitted designs for an aircraft capable of rising vertically, like the helicopter, and flying forward with a speed of up to 300 m.p.h. In these specifications a hovering ceiling is required of some 5,000 feet, with a service ceiling of up to 16,000 feet.

As everyone appreciates, the problem is not without its mechanical complexities. We can assess them briefly in our minds when we consider that the requirement for such an aircraft is for a propulsive mechanism in the form of a rotor or airscrew capable of changing its axis and directional thrust in flight, from the vertical to the horizontal and back to the vertical for hovering and slow descent. Those requirements cover a complexity of technical considerations. The higher power output demanded from the power plant in the initial climb of the helicopter has hitherto been quite a problem for the conventional piston engine to overcome, but the arrival of the gas turbine with its high power output per lb. of weight may perhaps offer one or two solutions.

With these few words I will turn to Captain LIPTROT and extend to him the invitation to continue with his paper.

CAPT. R. N. LIPTROT

It is fitting that at today's session we should have present the President of the Royal Aeronautical Society, since the Convertible aircraft in most of its forms attempts to combine features both of the fixed wing and rotary wing types of aircraft, and introduces problems common to the two types. It is a development in Aviation which is extremely controversial and I hope that the discussion which follows my paper is going to be full of interest.

Fundamentally the convertible aims at getting the best out of two worlds, and its object is to create an aircraft capable of a speed range wider than either the fixed wing or rotary wing types can give in themselves. As the helicopter already flies at zero speed the question resolves itself simply into a search for ways and means of raising the top speed of the helicopter, or, if you like, of giving the conventional aeroplane the landing and take-off qualities of the helicopter. I prefer to treat it from the former aspect because the problem, I think, becomes clearer in that way. Both types have their own limitations. With the fixed wing aeroplane the price which has to be paid for higher operating speed is usually higher take-off and landing speed, necessitating long and very expensive runways, unless the higher speed is obtained by sheer horse power, in which case the penalty is a deterioration in the economics of operation, while with the helicopter we have limitations mainly associated with tip-stalling and compressibility effects on the advancing blade. Many of the limitations in both types can be, and are being, overcome as research proceeds and our knowledge increases, but the designer cannot hope to escape all of them. The achievement of zero or very low minimum speed with very high operating speed can only come from the use of different principles at the two ends of the speed range, and in attempting the combination we have to be careful that the two principles are not mutually incompatible and do not cause undue interference one with the other. The idea of convertibility crops up in all branches of engineering and is a favourite ground for inventors, but very few convertible ideas have any usefulness. In fixed wing aircraft we have many times in the past attempted convertibility, or rather dual purpose types, but in every case with which I am familiar the severe compromises neccessary to achieve the dual role have resulted in types which failed in their object. Indeed the only successful examples of which I can think in any branch of transport are the submarine and the amphibian aircraft, and, in our night life, the bed-settee. I mention this in order to stress the fact that in attempting to develop convertible aircraft we must be careful that our compromises do not lead to failure in achieving the end in view. I would say that the lower the degree of convertibility the better are our chances of success.

You may ask " Why do you want faster helicopters when you have already given us controlled flight at zero speeds and helicopters which can land on roof-tops, and you have time after time demonstrated that a helicopter flying at 100 m.p.h. is the faster means of transport over stages of, say, 250 to 300 miles." The truth is that operating speeds of the order of 100 m.p.h. such as are given by present-day helicopters, are not fast enough for airline operation where it is the block speed, in the face of the most adverse head-winds likely to be encountered, which controls in large measure the economics of operation and determines the attractiveness of the schedules which can be offered to the fare-paying passenger. For these reasons the operating speed of the helicopter must be raised and some of the forms of the convertible show the way to do this.

POSSIBLE CONFIGURATIONS.

The possible combinations of rotating and fixed wings are legion, but they all fall under three headings.

CATEGORY 1. In which the fuselage attitude is normal whether in the low speed or high speed regions of flight. Here we have several possibilities.

(*a*) The extreme case in which fixed and rotating systems are provided, each of which is sufficient in itself for one end of the speed range. This is simply a normal fixed wing aircraft with a supplementary rotating system, which is only operative at take-off and landing. Such proposals involve too much added weight and drag and reduce payload prohibitively. To reduce the drag, the rotors are usually arranged either to take up a trailing position when inoperative, or be stowed away by retracting into a fairing or the blades being made to telescope, so increasing the mechanical complexity still further.

(*b*) A half-way house in which the supplementary rotating system is not big enough to sustain the aircraft in flight at zero speed, but only contributes a certain amount of lift, so reducing to some extent the take-off and landing distances. Here again the rotor weight reduces payload and the rotor must be retracted or have telescope blades. In some proposals of this kind the rotors are carried in holes in the main plane. They reduce the effective area of the main plane, and are so small that their lift contribution is of no great value. The rotors may be driven as helicopters or simply allowed to autorotate.

(*c*) In which a two-bladed rotor is stopped and locked athwartships to become a fixed wing after conversion. Very often there is a permanent fixed wing so that the conversion is a biplane. Most proposals of this kind have a separate propulsive means for high speed flight though. Where the rotor is jet propelled, the blade tip jets may become the main propulsive means. The method involves rotating one blade through 180° in the jet propelled version or when normal aerofoil sections are used for the blades. This added complication can be avoided by using aerofoils of lenticular shape when the leading and trailing edges become interchangeable.

Historically this type is of interest, since in 1937 HERRICK, an American, demonstrated the first conversion in the air of his " Vertoplane," which was a biplane with normal tractor airscrew in which the upper wing could be released, and operate in autorotation as a gyroplane rotor. The aircraft took off as a normal biplane, could cruise either as a biplane or as a gyroplane and landed as a gyroplane. The conversion in the opposite sense from gyroplane to fixed wing was never accomplished. For the " Vertoplane," HERRICK developed a double-purpose symmetrical aerofoil which proved to be reasonably efficient in both regimes of flight.

HERRICK is still advocating what is basically the same type, and currently is enaged on the design of a new aircraft in which helicopter take-off and landing is provided by driving the rotor by jets at the blade tips. The controls are quite conventional and operate in the same way in any regime of flight, except that a separate collective pitch control is provided for flight as a helicopter. The process of take off and conversion is to take off as a helicopter with the jets operative. Then after vertical climb to a convenient height the stick is moved forward to accelerate to some 40 m.p.h., when the conversion lever is moved to the gyroplane position. Automatically the tractor airscrews rev. up, the jets are shut off and the rotor blades set at the angle for autorotation, and the aircraft is flying as a gyroplane. When a speed of about 70 m.p.h. is reached the conversion lever is put into the " plane " position, automatically the rotor is slowed down, stops, and then reverses for not more than half a revolution when the locks come into operation and the rotor becomes a fixed wing. The landing conversion is effected in the reverse order, the jets being automatically re-lit prior to the final deceleration to hovering and touch down.

(*d*) In which the rotor(s) are rotating in a substantially horizontal plane for take-off and landing, and are rotated through 90°, either alone, or with the fixed wing, for high speed flight. In most of the projects which have been put forward two rotors are disposed laterally near the tips of the fixed wing. An alternative which has been proposed is to have an intermeshing twin rotor group at the nose of the fuselage. The engine, with transmission and rotors, is carried on a trunnioned mounting and the whole assembly swings through 90° during conversion. In this category the rotors become the propeller for cruising flight and we have the same problem as is discussed in connection with the second main category.

(*e*) The remaining type in this first category is that in which the rotors continue to operate as helicopters in all regimes of flight, but are progressively unloaded as forward flight speed increases by means of a small fixed wing. It may be argued that in putting this forward I am begging the question, since it is not a convertible at all, but simply a composite type consisting of a normal helicopter to which a small wing has been added, and that there is no conversion either mechanically or in attitude. Such a use of a small wing, however, is capable of extending the speed range of a helicopter to a

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very considerable extent and is legitimately within the scope of this paper, and indeed I am going to argue that this is the logical and radical way of improving helicopter high speed performance. It moreover satisfies my dictum that the less the degree of convertibility the greater the chance of success in achieving the object of convertibility, which, as I have said, is fundamentally to improve the high speed performance of the helicopter. It is well worth while I think to elaborate this theme. There are two fundamental factors which operate to limit high flight speeds on the helicopter.

(i) *Compressibility effects*, since very high speeds are encountered at the tip sections of the advancing blade. Frankly we do not know the limiting Mach No. to which we can go without risking any severe rise in profile drag power, but so far most helicopter designers, accepting high speed aeroplane evidence, have put the limit at about 0.8. The high Mach No., however, is only experienced over a small part of the rotor disc, and under conditions where the blade section lift coefficient is low, so perhaps we can accept a somewhat higher figure than 0.8 as being permissible. Tentatively I have personally used 0.83.

(ii) *Tip stalling on the retreating blade.* The parameters which are decisive in determining when tip stalling commences, other than the blade aerofoils characteristics, are the tip speed ratio and the aerodynamic blade loading $\frac{C_T}{\sigma}$. (C_T is the thrust coefficient defined by $C_T = \frac{\text{Thrust}}{\pi R^2 \rho (\Omega R)^2}$ R being rotor radius and ΩR the tip speed. σ is the solidity defined here as the ratio of total blade area to disc area).

The higher the tip speed ratio the more severe the tip stall which is encountered. This, of course, is due to the fact that for rotors with hinged or see-saw blades the automatic equalisation of lift between advancing and retreating sides of the disc leads to an increase in blade angle of attack on the retreating blade. The blade angles are also influenced by the drag characteristics of the helicopter, since the greater the parasite drag, the greater the tilt of the disc necessary to provide the propulsive component of the thrust for forward flight, and therefore the greater the blade collective pitch which is necessary. The aerodynamic blade loading parameter $\frac{C_T}{\sigma}$ is proportional to the rotor blade loading, and is inversely proportional to the square of the tip speed. It is a measure of the mean blade lift coefficient and obviously the blade stall at increasing flight speeds will be more severe the higher the aerodynamic blade loading.

We have only one report (N.A.C.A. Tech. Note No. 1083 by GUSTAFSON & MYERS) which gives us any guidance as to the maximum blade angles which can be permitted before the ill effects of tip stalling in vibration and impairment of handling qualities become intolerable. The conclusions from flight tests were that the effects of tip stalling begin to be noticeable at retreating blade angles 12° above the no-lift angle, and become too severe to permit flight at 16°. For the purpose of this paper I have assumed that 13° would be tolerable for an airline helicopter. Perhaps the best way of showing how the parameters are related is to plot the rotor $\frac{C_T}{\sigma}$ necessary to obtain the desired limiting tip blade angle at any tip speed ratio, the influence of parasite drag being shown by plotting a family of curves against μ, each curve being appropriate to an assumed value of D/L, the parasite drag/lift ratio at the operating speed corresponding to each point on the curves. I have worked out the theoretical relationship between $\frac{C_T}{\sigma}$ and μ to give my assumed limiting blade tip angle of 13° and give it in Fig. 1. Of the three drag curves, that for D/L = 0.1 is representative of the high drag helicopters now in use, while that for D/L = 0.05 may be taken as representative of the next generation of aerodynamically " clean " helicopters.

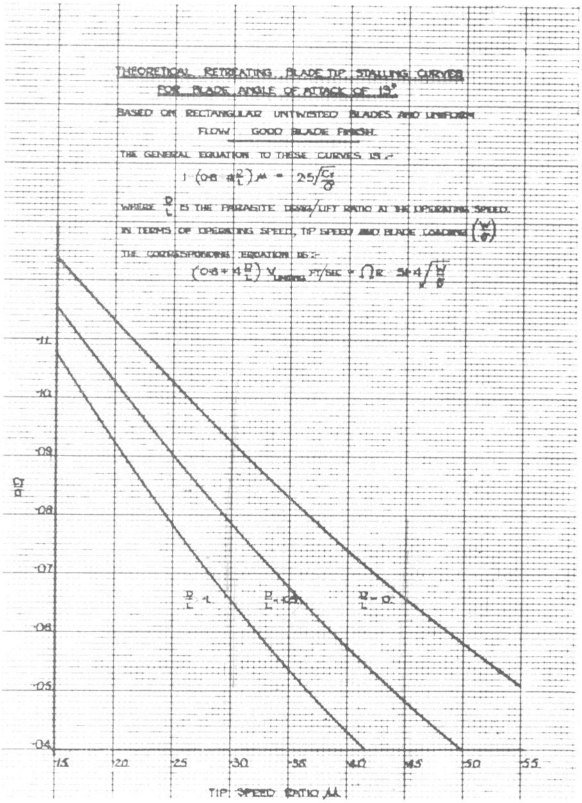

Fig. 1.
Chart showing theoretical retreating blade tip stalling curves for blade angle of attack of ~~*19°*~~ 13°

These curves show how decisive $\frac{C_T}{\sigma}$ is with respect to tip stalling, and in particular how rapidly the operating $\frac{C_T}{\sigma}$ must be lowered with increasing speed to maintain the same retreating blade tip angle.

At this point, I wish to express my thanks to Mr. Rowe and British European Airways for permitting me to use this material, which was worked out while I was employed by the Corporation.

As is well known, the optimum hovering performance of a lifting rotor occurs at a value of $\frac{C_T}{\sigma}$ of 0.1, and if we are to maintain reasonable hovering performance we cannot reduce $\frac{C_T}{\sigma}$ much, certainly not below 0.07, so the problem of raising the high speed performance of a helicopter resolves itself largely into finding means of reducing $\frac{C_T}{\sigma}$ appreciably in forward flight as compared with the hovering value, and of reducing rotor tilt, and we have the following means available :

(1) *The Gyrodyne.* The gyrodyne principle of putting part of the power available into a propulsive screw(s) is in effect equivalent to reducing the drag of a helicopter to a negative value. Fig. 1 shows how effective this is in raising the operating speed as limited by tip stalling. It indicates that we might expect to raise the limiting speed to something like $\mu = 0.45$ at a $\frac{C_T}{\sigma}$ of 0.07. As the limiting tip speed for advancing blade Mach No. 0.83 is about 620 f.p.s., this corresponds to a limiting operating speed of 190 m.p.h., a very considerable advance over anything today.

(2) *The use of small fixed wings.* The radical way to lower the $\frac{C_T}{\sigma}$ for high speed flight, while keeping efficient values at the low speed end of the range, is to add a small wing to take over part of the lift in forward flight and so progressively unload the rotor, and lower the operating $\frac{C_T}{\sigma}$ with increasing forward speed. Some recent design studies showed that operating speeds of 200 m.p.h. were quite possible by adding a fixed wing only 3% of the rotor disc area. There is a limit to the amount of fixed wing which can be added since the unloading of the rotor means that it must be tilted further forward to provide the thrust component. I have not yet completed my investigation, but preliminary work indicates that up to 6% of the rotor disc area can be used. Moreover, the gyroplane principle can be used still more effectively with small wings, and there is not the same limitation on the amount which can be used since the rotor is never tilted appreciably. So far as the investigation has gone it shows that a gyrodyne with 6% fixed wing would have a limiting speed of about 250 m.p.h.

It is clear that the combination of helicopter with a small fixed wing is a relatively simple but extremely effective device for raising the operating speed of the helicopter, and makes any real convertibility quite unnecessary, at any rate where speeds of the order of 250 m.p.h. are satisfactory, as they are for the relatively short range airliner. I would say that from now onwards every helicopter design should have small wings, or at least provision for adding them during development, since the advantages which they confer are so outstanding. Analysis of the overall aerodynamic efficiency of the pure convertible of the type where the rotor is turned through 90° to become the propeller, and of the gyrodyne with fixed wings, shows that the convertible can only have a small advantage, of the order at most of 10%, in limiting speed. It pays heavily for this small advantage in its greater complexity.

The helicopter with small fixed wing is being exploited by the Gyrodyne Company of America. Their prototype weighs 7,600 lbs. gross, with a bare weight of 4,650 lbs., and has a small fixed wing of 26 feet span and 75 square feet area. It has two coaxial contrarotating rotors, each 52 feet diameter, driven by two Lycoming Engines each developing 375 h.p. It cruises at 150 m.p.h. at 5,000 feet, using 608 h.p. At this cruising condition the wing is carrying 2,500 lbs. weight so that the rotors have only to develop 5,700 lbs. lift.

CATEGORY 2. The second category of convertible is that in which the aircraft is postulated as taking off with the fuselage vertical, the whole aircraft being rotated through 90° for high speed flight, and we have two classes.

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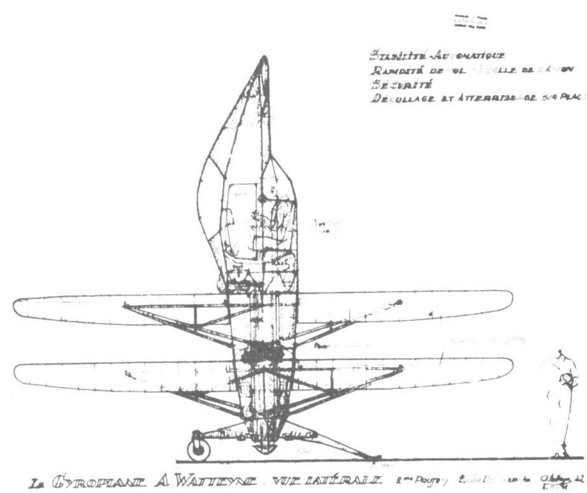
(*a*) In which a permanent fixed wing is provided to give necessary lift in horizontal flight, and the rotors become the propellers.

The major difficulty in all cases where the rotor becomes the propeller after conversion, whether in the first or second category of convertibles, is that of designing a rotor which will be efficient both for vertical lift and for propulsion in high speed flight. I hardly think it necessary here to go into details. It will suffice to point out that high efficiency in vertical climb is associated with high solidity, light power loading and light disc loading, the latter demanding large diameter, while in horizontal flight high propulsive efficiency demands low solidity and small diameter. In other words the rotor size for good helicopter performance is too large for best efficiency in horizontal flight. In order to avoid the additional complication of variable gear ratio in the rotor drive, it is also desirable to have substantially the same rotor speed in all flight directions. A compromise is necessary if we are to keep the $\frac{C_T}{\sigma}$ as high as possible for helicopter flight and as low as practicable for horizontal flight and a severe loss in propulsive efficiency is inevitable. This loss tends to increase very rapidly with increasing forward speed, particularly in the absence of a variable gear ratio, and the selection of rotor diameter is a matter for intensive study. If we are to have reasonable propulsive efficiency the rotors must be primarily propellers, with much higher disc loading that is customary for helicopter rotors, and some other expedient must be adopted at the low speed end of the range. The solution devised by ZIMMERMANN is to use an all wing aircraft of aspect ratio close to unity, with two rotors bathing the whole wing in slipstream so exploiting the high lift developed at high incidence by low aspect ratio aerofoils as well as the lift due to the slipstream at low forward speeds. (Fig. 2B).

(*b*) In which the rotor is stopped to become a fixed wing on conversion. In this case either a separate propulsive means must be provided or the rotor be jet propelled, in which case the jets can be the propulsive means.

Fig. 2A



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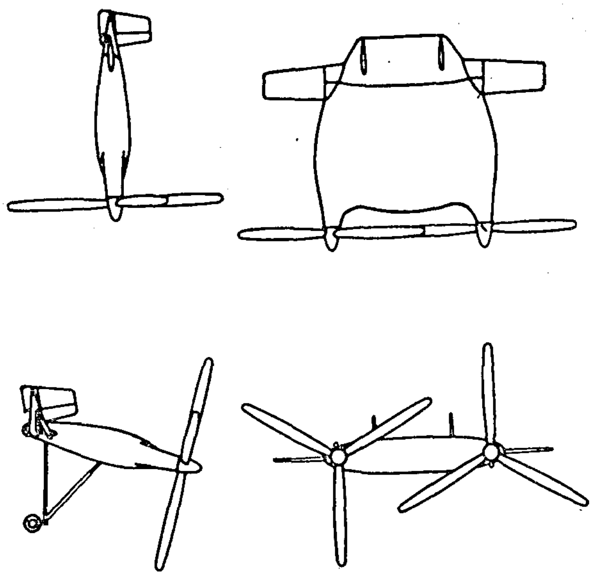

Fig 2B

CATEGORY 3. This survey of the usual configurations adopted for convertible aircraft has shown that except perhaps ZIMMERMAN'S low aspect ratio type, they cannot be expected to achieve much more than the 250 m.p.h. which is within the promise of the relatively simple addition of a small fixed wing to an otherwise conventional helicopter. For some service roles, particularly for fighters to operate from the decks of ships, where higher and yet higher performance is demanded while deck limitations remain the same, a high performance convertible would be most attractive, and there is one form of convertible for which a case can be made. This uses the side force experienced by a yawed propeller. This is, of course, a well known effect and all designers take due account of it when calculating the required fin area for a new type. To use this side force as the prime means of lift is, however, something quite new in aviation. The aircraft using this principle is of the tilting fuselage type with a jet propelled rotor or rotors of reasonable diameter and high solidity. With such a type in the horizontal position the combination of large diameter blades and high pitch results in considerable side projected area, and with the aircraft at small angles of pitch the rotor will create enough lift to sustain the aircraft. This principle was first put forward by HOLST in Germany and was used towards the end of the war by KURT TANK, the Chief Designer of the Focke Wulf Co., as the basis of the design of a novel high speed fighter. (Fig. 3).

This aircraft was to have a three-bladed rotor 37.4 feet diameter, driven by ram jets at the blade tips, the total blade area being 179 square feet, weighing 7,000 lbs. empty, with a gross weight of 11,400 lbs., the estimated maximum speed was 620 m.p.h. at sea level.

This would appear to be one line of development where the rotary wing type can approach the high speed performance of the modern aeroplane while at the same time giving vertical take-off. The possibility of such an

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achievement gladdens the heart of the deep dyed rotary wing enthusiast, but in spite of my having been the most persistent advocate of the helicopter for more years than I care to remember, I am going to be a thorough renegade and hand it on a plate to our conventional aeroplane friends by suggesting to them that they can themselves do just as well. Some of their jet propelled

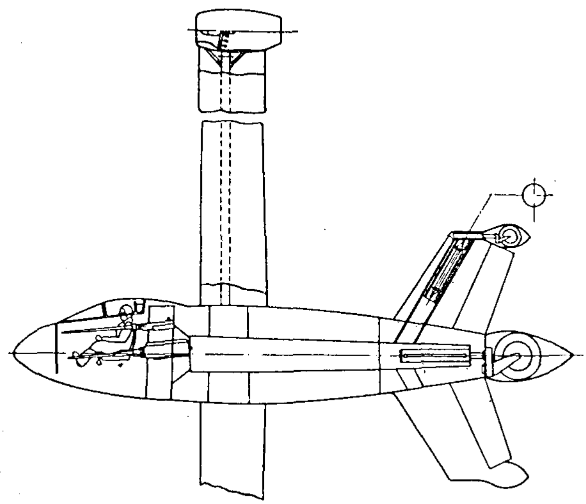

Fig. 3. PROPOSED HIGH-SPEED ROTOR AIRCRAFT BY KURT TANK

high speed fighters in the 600 m.p.h.-plus bracket already have a thrust weight ratio better than unity so that with a tail undercarriage they could in fact take off vertically. They, of course, would have some pretty problems as regards stability in vertical flight and they could never land vertically in the event of power unit failure. In aviation, however, the impossible always becomes reality sooner or later and perhaps the really high performance convertible might come about in this way.

FURTHER PROBLEMS

In a single short paper I can only touch the fringe of the convertible problem and many of those aspects which have had to be left out are in fact the very ones on which the eventual practical convertible must rest. Within the time available I can only briefly indicate two of them.

(1) A safe landing in the event of power unit failure is imperative. This accentuates the problem of designing a rotor which will be efficient as a propeller since the disc loading must be low enough to permit a safe autorotational glide with a low enough rate of descent.

In those cases where the rotors become the propeller we have a parallel problem to that of power failure in the helicopter proper. If power fails in horizontal flight during conversion of the rotors back to the condition with axis vertical they must pass from operation with the airflow down through the rotor disc, the windmilling zero torque condition to the other zero torque condition that of autorotation where the airflow is upward through the disc. During the transition from one type of flow to the other there is a period where there is a deceleration torque on the rotor and the question arises whether the rotor axis can be traversed quickly enough and the autorotative state established before the rotor slows down too much and without the negative thrust becoming so large that the wing is excessively loaded. This is a question which will have to be carefully considered, particularly where the rotor axis itself is rotated through 90°. The angular rate of movement from horizontal to vertical will have to be such that the whole change is completed within two or three seconds and as the main power unit is no longer available a separate power source will have to be provided for emergency conversion.

(2) The conversion must take place in a progressive and continuous manner without any loss of lift on the aircraft as a whole and no abrupt aerodynamic transitions can be tolerated. Throughout the whole transition period the aircraft must continue to be stable and under full control and the controls must continue to have the same response throughout all the phases.

One point, for instance, which will have to be carefully considered is that whether or not the rotors are used for lift in horizontal flight the lift and side forces will be present in greater or less degree, whenever there is any pitch or yaw and if the rotors and tail surfaces are not properly proportioned and located, the aircraft may become unstable in the high speed condition. An interesting point was disclosed by N.A.C.A. tests on the Zimmerman low aspect ratio type. Here the aircraft was definitely unstable with rigid rotors. Articulated rotors gave a stable slope to the pitching moment curves, but the tail controls were not powerful enough to trim at the very high angles of attack associated with high values of lift coefficient. The remedy was a large trailing edge flap used as an auxiliary longitudinal control. This flap was necessary in any event because of the pitching moment introduced by ground interference during landing and take-off.

Except for the N.A.C.A. research on the Zimmerman type, little has been done to systematically explore the many problems of the transition stage and most inventors have simply described their aircraft in the two operative configurations, assuming that the conversion can be effected instantaneously as though one had only to pull a lever or press a button. Unfortunately it is not so simple as that and much research would appear to be necessary before we can be assured of completely satisfactory conversion.

Conclusion.

My personal conclusion from all this is that, at any rate for airline operation where an operating speed of 250 miles an hour would be ample, the true convertible has little merit over the helicopter with a small fixed wing. It must be remembered that the helicopter is essentially a means of transport for relatively short distances. The convertible is not attractive for long stages because its overall efficiency is inevitably lower than that of its fixed wing counterpart, and the price which is paid to improve the take-off and landing qualities will diminish the benefits which are otherwise obtained from convertibility inversely as the stage lengthens. Mr. Shapiro recently put it very neatly when he said that the convertibility should be on the ground and not in the air. I presume that what he meant, and he is perfectly right, is that the conversion should be effected by a physical transfer of the passengers from the fixed wing air liner to the feeder line helicopter at the main inter-continental airports. If it is done that way we are then using the helicopter in its proper role, complementary to and not superseding the fixed wing type. For very high speed operation the driven wing principle, as in the KURT TANK type, seems to be the only one which offers an attractive solution.

Well, that is all. I hope I have not given you the impression that I am prejudiced against the convertible. I am not ; I yield second place to no man in my advocacy of rotating wing aircraft, and I am devoting all my efforts nowadays to improving the high speed performance of the helicopter, but so far as the convertible is concerned I do say that we have got to be realistic. We must not be led away by flight in the two extreme conditions : we must realise that the transition phase introduces a lot of research before we can be sure about it, so I think myself right in saying let us crawl before we walk and walk before we run, and for the next stage towards very high speed operation of an aircraft which can land vertically let us take the logical, rational course of putting a fixed wing on a conventional helicopter.

Discussion

The Chairman : I am sure you will agree with me that Captain LIPTROT'S peep into the future is a most exciting one. I must say that as a confirmed " rotary winger " his suggestion that fixed wings should be attached to helicopters seems to me to be almost a heresy, but I am sure he has given you much food for thought and discussion and I am now calling upon Mr. ROWE to be so kind as to open the discussion.

Mr. N. E. Rowe (*Member—British European Airways*) : To be called on to open the discussion is most unexpected, but there are certainly many points that we can all talk about, I think, in this paper. I find the paper really is a bit of a fraud, because while Captain LIPTROT calls it " Convertible Aircraft," he has really shown us how to turn helicopters into high speed aeroplanes. In other words, as I think it has been said before by someone, that the best way to make the helicopter a good machine is to add a little fixed wing. The point he is making here, though, is absolutely sound, that if we take as the objective of convertible aircraft higher forward speeds combined with the ability to fly vertically, then the simplest and most direct way to approach that at this stage is to progressively unload the rotor in forward flight at increasing speeds by adding some fixed wing, and I think all the work that he has done demonstrates this, and I believe that many of our speakers this afternoon will probably agree. Followed up logically it does lead to all these other developments of the gyrodyne principle which he has mentioned, since if one unloads the disc far enough in forward flight it is taking less and less lifting load therefore it has to be tilted forward more and more to provide the forward thrust necessary, and one runs progressively more into the stalling condition. But the true Convertaplane seems to me to offer a much more exciting proposition in a way since, although it may not be the sort of thing one looks to for civil air transport perhaps for many years to come it may, as he suggests himself, have applications to military needs which should be really very important. The fact that one of the most advanced German designers really was thinking very seriously about this shows that there is something in it, and with the advent of jet propulsion it seems to me that the true convertible, that is something with a combination of rotary wing plus fixed wing, with the rotary wings set in some way in order to obtain very high speed forward flight and at the same time capable of vertical flight for take-off and landing, is a distinct possibility.

In one of the types he talked about I think Captain LIPTROT said we could turn our existing types on end and they would take off but they would not be able to land in the same way without disaster. I do not think one can think of that as a true convertible, because it must be able to have vertical flight in the take-off and landing. As you know, for some time past there has been a lot of work going on to obtain a higher performance in fighter aircraft by taking the undercarriage off. Well, it seems to me that these convertible types, whilst adding some weight, without any doubt, in their rotating lifting system, would enable some compensation to be obtained by dropping the undercarriage, and that in fighter aircraft, perhaps having to operate in jungle and difficult conditions where these big airfields cannot be made, it might be an extremely attractive proposition. So that there are two scales to this thing. There is the steady advance where we obtain comparatively high cruising speeds from the development of the rotary wing aircraft as we know it today by adding progressively some fixed wing and propeller or jet propulsion, and things of that sort, and then there may be the possibility for military machines of the true convertible, which I would think is much more likely to be a stowable rotary wing for very high speed forward flights than something which rotates the whole axis of thrust from vertical to horizontal in the way some people have been working.

One of the interesting things which I would like to ask Captain LIPTROT is, in the event of such an aircraft becoming a feasible possibility is there any limit to the wing loading that one might expect in high speed forward flight? Can we, for instance, expect wing loadings of 200 lbs. to the square foot, or something of that sort, so that the fixed wing could go to vanishing point and one could expect very high speed performances? If that were possible, and if one could at the same time, by developing jet propulsion for the rotating element, practically guarantee no engine failure, it might be possible to design a very compact aircraft which would have a very high disc loading, and which would be perfectly feasible if one was quite sure of the engine, with a very high speed forward flight and with a very small wing.

Mr. O. Fitzwilliams (*Founder Member—Westland Aircraft Ltd.*): I agree very strongly with the general conclusion which Captain LIPTROT reached as to the possibility of high speed helicopter flight, but am rather puzzled as to why he should present his solution under the name gyrodyne or even as a novelty.

In about 1933 the old Pitcairn PCA-2 Autogyro was operating in flight at tip speed ratios up to 0.8—not 0.5 which you were considering possible this afternoon, but 0.8—and I have found it interesting to consider a possible family of aircraft which start out as normal helicopters and which, as they go faster and faster, go, as it were, backward in time.

For instance if, in the interests of easy maintenance, one likes to put the mechanical bits "outside the outside," one way of doing that is to put the engines outside on lateral outriggers, in which case you have a configuration to which you can easily add airscrews and a fixed wing. You can go fast by using the wing to unload the rotor, but if you go very fast indeed then, as in the old Autogyros, the controls must be on the wing as well, as the rotor is doing nothing.

I wondered, when Captain LIPTROT was speaking of very high speeds, in what detail he has thought of the condition of the aircraft at those speeds? Even if it were not intended to take the whole weight on the wing, the sensitivity of the wing to changes in pitch is likely to be much greater than that of the rotor, and consequently at some time or other, especially in the case of power failure, there will be a serious danger of taking the whole weight on the wing and thereby letting the rotor slow down. Points like that raise the question of how far one can push this solution. My impression, from looking at some quite attractive design sketches, is that one does not want to go very far in that direction; that something like half the horsepower might go into the propellers but that more might give trouble; and that generally one sought to aim at a fairly modest speed. Perhaps 180 miles an hour is as fast as one can expect to go in this manner.

I was very interested in Captain LIPTROT'S suggestion of simply putting a fixed wing on a normal helicopter, without propulsive airscrews. Here again the advantage claimed in the unloading of the rotor, but if a substantial proportion of the lift is to be taken on the wing, then the wing must be of a reasonably large span. In the particular case of an XR5 helicopter, to which a wing of low aspect ratio was fitted, I believe the wing took a considerable proportion of the weight and the resulting induced drag did more damage to the stalling of the blades than the good done by the wing in unloading the rotor. Also, although the rotor was to some extent unloaded, the stresses in the rotor blades continued to mount with increasing speeds without any relief from the lift of the wing—a point which should perhaps be taken very seriously.

Those who are familiar with the S.51 will remember that it has several strong points, such as those originally used for the attachment of the R.5 undercarriage, which are suitable for the attachment of a wing. We can also fit an adjustable tail-plane so that one of these machines, suitably modified, might teach us quite a lot along the lines suggested by Captain LIPTROT.

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Mr. J. Shapiro (*Founder Member*) : I think it is very important, in considering developments of this kind, to have a very precise idea of what we want to achieve. And I believe that we want to achieve a cruising speed of 180 m.p.h. I am entirely in agreement with the previous speaker, who said that we might think twice before we actually consider these combined systems with speeds up to 250 miles per hour. There is an economic barrier and I have come to the conclusion that it is somewhere around 180 miles per hour.

I believe that there is an underlying sense in it, not only from the engineering side but from the purely human point of view. The value of speed should be looked at in this manner : if we have, let us say, a service from London to Birmingham, then at first it is undoubtedly valuable to reduce the time of the journey, by increasing the block speed, but there is a point at which nobody would think of paying any more or would value the service any higher. I should say that this figure is somewhere around a quarter of an hour or twenty minutes between London and Birmingham. When the time of a journey becomes an insignificant proportion of the average time that a passenger spends at his destination then speed has no intrinsic value any more in transport. I think that, since the range of a helicopter is limited to a few hundred miles, its useful speed in transport is also limited.

In addition I would like to point out that whilst we can, on the basis of fairly reliable calculations, predict the performance of a combined system up to 180 or 190 miles per hour, beyond that we have to rely on experiments because we then get into conditions of tip speed ratio which have rarely been examined. It seems from a number of experiments such as those mentioned by Mr. Fitzwilliams that we have been too pessimistic in predicting the performance of rotating wings at very high tip speed ratios. It is an unknown field and worth while exploring, not so much from the point of view of the civil air liner as from the point of view of several other applications and mainly, perhaps, from the point of view of a military transport. I do not see any reason why we should not put rotors on Lancasters and fly them around at very high speeds and learn something about them.

There is one detail feature of the Focke Wulf Convertible project proposal which Captain Liptrot has left out and which I think is extremely interesting. I am merely quoting figures which I have seen in these German reports. Even if we forget the fact that a hypothetical fixed wing ram-jet fighter cannot land vertically—assuming that the pilot can parachute down or something like that—there is still one respect in which, on paper, this convertible project is very much more attractive than the fixed wing ram-jet fighter, and that is range. The range of two fighters, each embodying, so to speak, the most hopeful achievements of jet propulsion as they were envisaged in 1944, is roughly like two to one. Whilst all the other performance parameters are approximately equivalent—the same rate of climb, the same maximum speed—the convertible fighter goes about twice as far.

Another point about this particular proposal, is that the conversion problems in such an aircraft are probably very much simpler because it has virtually no fixed wing at all, and normally the real aerodynamic problem is between fixed and rotating wings. In fact as you have heard from Mr. Fitzwilliams you can get a combination which is bad in both respects.

One other remark which I wish to make is again on the question of the desirability of a convertible aircraft for very long-range air liners. There have been some American proposals in that direction but I think the existence of the helicopter should be a help to designers of long-range air liners in the sense that they should really make use of it as a principle of organising air traffic. If they do they will probably produce more economical types, and it is in this sense that I refer to "conversion on the ground," because what we have today is, in fact, a kind of convertible fixed wing aircraft. The flaps convert it from an aircraft with a small efficient wing into one with a larger inefficient wing, and a lot of weight and complication is required for this purpose. All this could be simplified if the fixed wing people knew that they could rely on a feeder service by helicopter, and operate from long and remote runways

Mr. N. E. Rowe : There is just one comment I wish to make on the question of speed. I think it is perfectly sound to say we should not strive for increasing the speed of the existing helicopter unwisely and just as something to be achieved, but there is most certainly a need for increasing speed in the air transportation field. Firstly, regarding the times to Birmingham, as the previous speaker says, beyond certain speeds there is very little to be gained. One thinks, of course, of going beyond that distance, say from London to Edinburgh or Glasgow, and stopping at various places *en route*, and then the total time can be very considerably affected by increasing speeds and hence be made much more attractive to passengers, even although the intermediate times between the stopping places are not very much affected.

The second point is the incidence of high winds. In our work with helicopters in this country, when trying to fly regular scheduled routes, we have found the incidence of high winds affects our punctuality greatly, or would do so if we did not schedule to meet the winds on a high percentage of occasions. That means, of course, the cruising speed is very much reduced if one is going to obtain regularity and punctuality, and therefore the times can be greatly improved by improving the cruising speed, and the regularity and punctuality can be correspondingly improved. Those are the main factors, I think, and for that reason I have been advocating for nearly all the time I have had anything to do with this that we do want high cruising speeds for helicopters, and we do want to get somewhere in the region of the 180 or 200 miles per hour mark. It is quite a fair objective and is something we can expect to do without running into very severe problems of research on the way.

Mr. R. Hafner (*Member—The Bristol Aeroplane Co. Ltd.*) : The word " convertibility " is a loose term and has, I believe, at least two meanings. One speaks of " convertibility " when referring to a device which alternatively can perform *two functions*. An example for this case is the bed-settee mentioned by Captain LIPTROT, which is a piece of furniture suitable for sitting or alternatively, after appropriate adjustment, for sleeping. In another sense, " convertibility " is the combination of two or more devices in alternative arrangements so that performing of *one function* may be obtained in an improved manner. An example for this case is the sailing boat with the auxiliary engine. Whilst the " pure " sail symbolises the ideal of the sport so beloved by the yachting fraternity, the value of the auxiliary engine is recognised by every practical sailor and, therefore, the combination of sail/engine as a convertible arrangement has become a fundamental feature of the cruising yacht.

Coming now to the convertible helicopter, I consider that of all proposals quoted by Captain LIPTROT the most interesting for the near future is the combination of a rotor with a small fixed wing. It is just like the cruising yacht with the auxiliary engine.

I myself have been very interested in this idea for some time and have made tentative investigations. Indeed, I ought to tell you about some amusing incidences which have arisen from the announcement that we might one day have a small wing stuck to our helicopters. There were general smiles and in the fixed wing fraternity of our company it was said " at last the sinner is returning from his rotary adventures, obviously a wiser man," or " history is repeating itself, and this reminds us of the time when we were trying to make tailless aircraft and eventually, in the face of considerable difficulties, came to the conclusion that there was nothing seriously wrong with the tailless aircraft which could not be put right by quite a small tail-plane."

The problem, however, is not as simple as that. When we say we could use with advantage a small wing, we do not mean that we merely wish to transfer the job of weight lifting from the rotor to the fixed wing when flying forward, but we hope to obtain from this combination a new technological effect. Captain LIPTROT has pointed out that unloading the rotor reduces its $\frac{C_T}{\sigma}$ and thus permits a higher tip speed ratio, which, assuming the same speed limitation for the advancing blade tip, means a higher forward speed of the aircraft. With this I am fully in agreement.

I do not, however, follow Captain LIPTROT's arguments in connection with the " gyrodyne " principle. I have come to the conclusion that the main factors limiting forward speed, in addition to those already mentioned, are the coning angle and the blade shape, especially blade twist. It has been said that premature stalling of the retreating blade tip can happen with the orthodox helicopter owing to the high axial velocity component at which the rotor operates under the critical condition, but this stalling is not possible with the autorotating rotor or the gyrodyne rotor. In my view, such premature stalling at the blade tip, or at any other part of the blade, can always be avoided by suitable shaping of the blade, especially by longitudinal twisting. An ordinary propeller is designed, as we all know, so that it can operate efficiently in the axial flow, and I see no reason why a rotor should not be designed similarly so that the critical in flow condition, at the retreating blade, is met by suitable twisting of the blade.

In the discussion of the rotor-wing combination we have so far only considered performance. There are, however, many other equally important features which we must take into consideration before an actual design project can commence. There is the behaviour of the rotor-wing in the case of power failure or in gusts. We have to consider stability and stresses, to mention only two of a large number of knotty problems which the composite aircraft will present.

Finally, I would refer to the question of speed generally. Mr. SHAPIRO has expressed the view that speed with the helicopter has perhaps been over-emphasized. On the other hand we have heard from Mr. ROWE that if operating schedules are to be attractive to the public a high cruising speed is essential. I believe the key word here is " block speed." We are after a high block speed and with this in mind we must try to avoid conversion operation involving a serious loss of time. It must be remembered that the helicopter is operating on a short range and is, therefore, very sensitive to even minute time losses. We must make sure that the gain in time from the principle of converting is not all lost again by the actual operating of converting.

Mr. G. H. Tidbury (*Member—Saunders-Roe Ltd.*): I want to make a few points arising from design studies carried out on a twin-engine three-rotor helicopter. This work was commenced by the Cierva Autogyro Co. and is being carried on by Saunders-Roe Ltd. The lay-out lends itself readily to the addition of fixed wing area as there are outrigger booms which can be made of aerofoil section. An outboard engine installation was contemplated and, and Mr. FITZWILLIAMS mentioned, the installation of airscrews was a natural development. A particular design study was carried out for a machine with a cruising speed of 160 miles per hour, having a fixed wing area of 6.25% of the total disc area and assuming that the airscrews provided sufficient thrust to overcome all the parasite drag of the machine. This latter condition is not necessarily the most efficient, but provided a starting point for comparing the configuration with others. The economic aspect of this design compared very favourably with other designs considered. It must be mentioned that the design is not so ambitious in forward speed as were those of G/Cpt. R. N. LIPTROT when he suggested 250 miles per hour forward speed. Possibly this is because low tip-speed and the consequent advantage of efficient hovering were retained.

The design study included a general investigation of longitudinal control and stick fixed stability problems for machines of this type. It was found that with either a tandem or three-rotor configuration longitudinal control can be satisfactorily obtained by controlling the rotors alone, no control surfaces being required on the fixed aerofoils ; furthermore, it is possible to arrange the control in such a way that the control column is moved progressively forward with increasing forward speed. Incidentally, it appears from the calculations that the flapping angles involved are quite modest and no vibration problems should be encountered from this source.

I think that the investigation shows that the tandem and three-rotor configurations lend themselves to this medium stage of convertibility as natural developments of existing designs, and that they will be capable of meeting the immediate targets set this afternoon.

Mr. J. R. Anderson (*Member*): I seem to be the first, and I do not know whether I am going to be the last, of those to take up the cudgels for the aeroplane which takes off on its tail. I have been interested in this form of aircraft since about 1940—in fact ever since I was scared stiff a few times by staggering off the ground in bombers, and wondered why on earth we had to do that when we had the power to fly at high speed as well as maintain ourselves in the air.

A result of my research and work in the years between is shown by the models (see Figs. 4 and 5), in which propellers are selected to give optimum efficiency in the design condition, and are large enough to allow normal controlled descent on reduced engine power. That is, in the case of a twin-engined machine like the fighter, a normal controlled landing can be made on one engine, and in the case of the four-engined passenger 'plane it can be made on any two engines.

In flight the propellers provide lift as well as thrust, as Captain LIPTROT has mentioned. I do not know the date on which the use of this side force for sustaining aircraft was suggested in Germany, but I put forward to the Ministry of Aircraft Production in 1942 proposals for aircraft using this principle, and discussed them with Captain LIPTROT. Maybe they were in such an erudite form that he did not then get what I was meaning, but I am glad that he has now come round to believing that you can get side force from a propeller. I am in agreement with his views that in combining zero speed with high operating speed, the means adopted at each end of the range should not be incompatible or cause undue interference.

My designs fulfil this requirement because at high speed the propellers are working more efficiently than is possible with orthodox small propellers—this is accordingly taking up the cudgels against Captain LIPTROT's contention that you need small propellers at high speed—and also at take-off and landing. The wings are working at maximum L/D in the design condition, or may be selected to suit any special requirement. As they are positioned in the pulsating airflow from the contra-rotating propellers they will add to the thrust of the propeller when the fuselage is vertical, because of Katzmeyer effect. Mr. SHAPIRO mentioned the bad effect

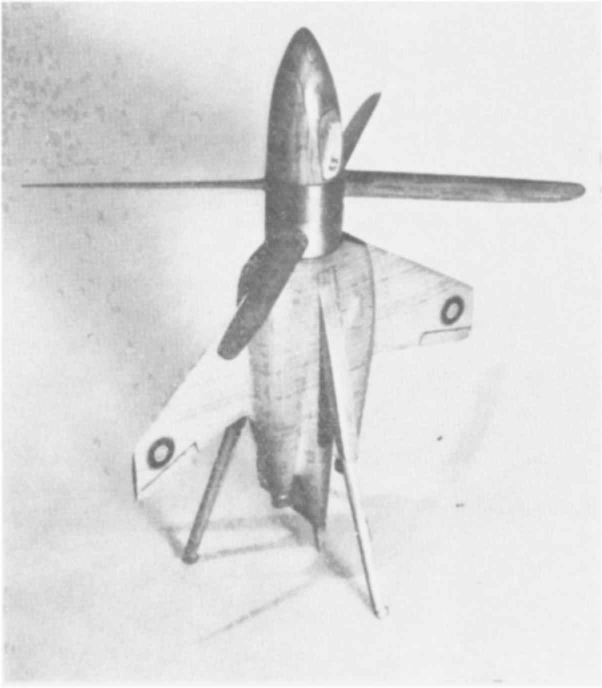

Fig. 4

of the single rotation propeller on any fixed wing, but with the contra-rotating propeller we have a pulsating flow and get Katzmeyer effect. You are probably *au fait* with it, and it is, that an aerofoil in a pulsating flow can have a reduction in drag, or exhibit thrust instead of drag. There are a number of papers on it. Fundamentally it amounts to the wing extracting energy from the pulsating airflow which would otherwise be wasted. A natural example of it is that of a bird soaring close to wavelets on water. It can go a very long way without effort. Another example is the Proctor which won the Round-the-Coast Air Race. It flew very low the whole way and its increased performance thus gained beat the handicappers.

The method of adapting a large propeller to an orthodox aircraft, as in my design, and standing it on its tail for landing and take-off, is the logical way of achieving our aim, because it can be done.

It is impossible to give a helicopter the performance of an orthodox aircraft. So there are two categories : one, the helicopter, should still be carried on with, and I agree it is a very good scheme to add wings to it ; but we also want parallel development on aircraft which stand on their tails and take off and land in that manner.

With regard to the types of machine with swivelling rotors and so on, which Captain LIPTROT has detailed in Category 1, I think they are ruled out because of

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their weight and complexity and also because of their poor performance. Also they are trying to do something without adequate power. Most of those which Captain LIPTROT has mentioned are machines which were being developed before the War, with the exception of the Focke Wulf machine, and they have had to use such arrangements because they had not the power for low weight which gas turbines give us.

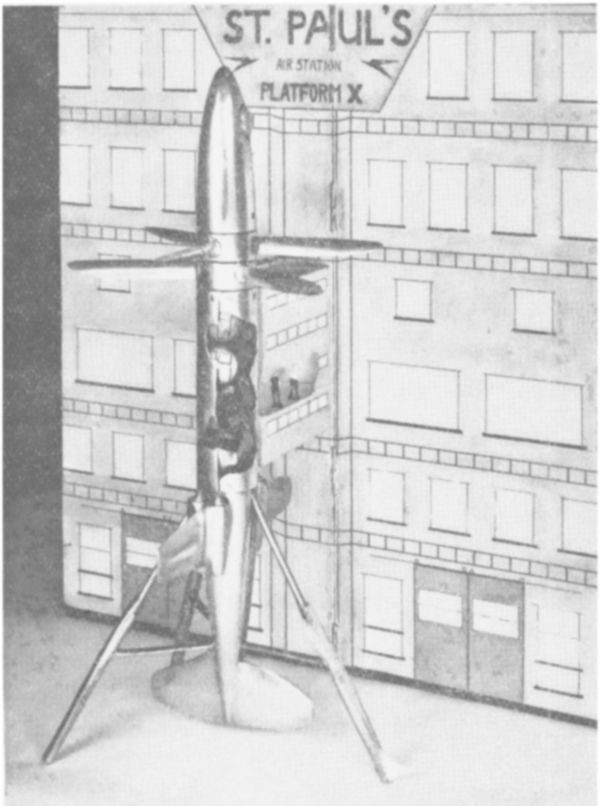

Fig. 5

Captain LIPTROT's suggestion of fitting wings to helicopters will undoubtedly add speed and make them more useful. The wings will need to be located away from the rotor outflow otherwise the machines will resemble the fellow trying to pull himself up with his boot-laces. In fact, unless they are out of the outflow they will bring the machines into the category where the two things are mutually incompatible. Of course, I know Captain LIPTROT is only going to use three per cent., but still for a helicopter like the Bristol 173 I presume they can position the wings out of the outflow from the rotors. It is clear, however, that helicpoters or gyroplanes will never be able to give anything like the performance of fixed wing aircraft, or my design, because of the limitations of tip stalling on the retreating blade and compressibility on the advancing blade.

The last lecture of this Association, on Rotor Stations, emphasised the fact that helicopters do not take-off and land vertically in practice, and that until we have aircraft which do so, operation from built-up areas, which is what we want, will not be a practicable proposition. One way of doing this is to put more power into helicopters, but if this is done the extra power cannot be used to give more speed

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in level flight because of compressibility and tip stalling, and unnecessary weight will be carried. For these reasons it is surely profitable to exploit aircraft as in my design, which can take off and land vertically and have higher performance figures than orthodox aircraft of the same power, because they have small wings and their drag is less.

I think that Categories 2 and 3 of Captain LIPTROT'S paper, dealing with machines taking off and landing with the fuselage vertical, and flying normally, should be considered together. The reason is that propellers large enough to take off and land such aircraft will always provide lift when in horizontal flight. The propellers should not be larger than is necessary, and fixed aerofoil area can then be added to give the machine the characteristics which are desired. For instance, the fighter model (Fig. 4), has a large wing to give the manoeuvrability at considerable altitude. A low-level attack aircraft, or one for regaining the speed record for Great Britain, would have a very small wing, more of present-day tail-plane proportions. The passenger model shown (Fig. 5), has a very small wing, and that wing is the correct size to work at maximum L/D in the design condition of 450 m.p.h. at 8,000 feet —taking 8,000 feet so that we do not have to pressurise, because we are going to use the aircraft over such short distances that it is not worth while to climb up to a higher altitude. If operation at lower altitude is desired, then a smaller wing is possible. There is no compromise at all on the wing area.

Now what is in a name? There is nothing " convertible " at all in such an aircraft as that, and I think we should drop this word, which appears to be of American origin. In 1942, Captain LIPTROT used to call it a direct lift aircraft, and I think that is a much better name than " convertible." Surely we should not slavishly follow America with this type, which is the subject of much work there, in the same way that we have tagged behind them with helicopters. If we do not watch out we shall be behindhand. I think " helicoplanes " is a much better word ; I know it has been adopted as a trade name in America for an orthodox 'plane with slow landing speeds, but it is a better word.

I covered the aspect of engine failure in that if an engine fails with the transport model another is available. Take-off is made on four engines, and landing on four engines, and when cruising only two are in operation so that they can be run near maximum output at the best operating point of the turbine. If one turbine fails another can be engaged. If two turbines fail then the pilot would be ordered to make a normal controlled landing in any spot at all. He does not have to worry in this case about having to salvage the aircraft. It would land vertically for repairs, and be taken off again. Not like the ordinary aircraft, which the pilot has to flog and try to get to an aerodrome if an engine fails. We want multiple engines, and it is recognised now, I think, that helicopters in any case want a spare engine so that they can fly over built-up areas in safety.

That leaves us with the fuel problem—if an aircraft which stands on its tail runs out of fuel on all engines. The scheme is, that instead of taking the fuel pipe from the bottom of the tank it is taken from higher up on the rear end. When the axis is rotated through 90 degrees for vertical descent a reserve of fuel is always available for landing. (See Fig. 6).

With regard to the propellers on such aircraft, Captain LIPTROT has made the statement that in horizontal flight high propulsive efficiency demands low solidity and small diameter, and I think this gives the impression that the faster the aircraft goes the smaller the diameter of its propeller should be. This is wrong, and it is well known that the main requirement for high efficiency is low blade loading. I think we all know that propellers are compromises on orthodox aircraft because of ground clearances and so on, and rarely does a propeller designer fit a propeller with as large a diameter as he could use to give the highest efficiency in the high speed condition.

Publication R. & M. 1992 compares five propellers and gives curves of their efficiencies, and to enable the comparison to be made the authors have put the power to give optimum efficiency into each propeller. In other words they have juggled with their power and have plotted their maximum efficiencies for speeds up to 600 m.p.h. That for a Spitfire, for instance, is 89 per cent. at 350 m.p.h., dropping off to 77 per cent. at 500 m.p.h. Now in practice orthodox small propellers are usually much too highly loaded to give 90 per cent. It is only when the loading is decreased that it is possible. In the paper it says : " It is clear, for instance, that at the highest forward speed a considerably greater power than that considered would be required to overcome the aircraft drag, and that either an increased number of blades or an increase in solidity or diameter would be needed."

In 1944 I sent a paper to the Ministry of Supply, demonstrating in detail the increase in propeller efficiency and the performance of an aircraft with a big propeller over a Spitfire with a similar engine, together with detailed propeller calculations checked by experts, but I am afraid Captain LIPTROT cannot have seen that. My paper shows that to do this with piston engines we need additional gearing, which I agree is a complication, but gearing was also considered a complication once on motorcycles. Who would imagine a motorcycle or a motorcar now, without a gearbox to make use of the engine power at high efficiency at low speed, and at high speed ? The efficiency of the transmission of power is very much more important in aircraft than it is in motorcars, because we know the old Service saying, " What goes up,

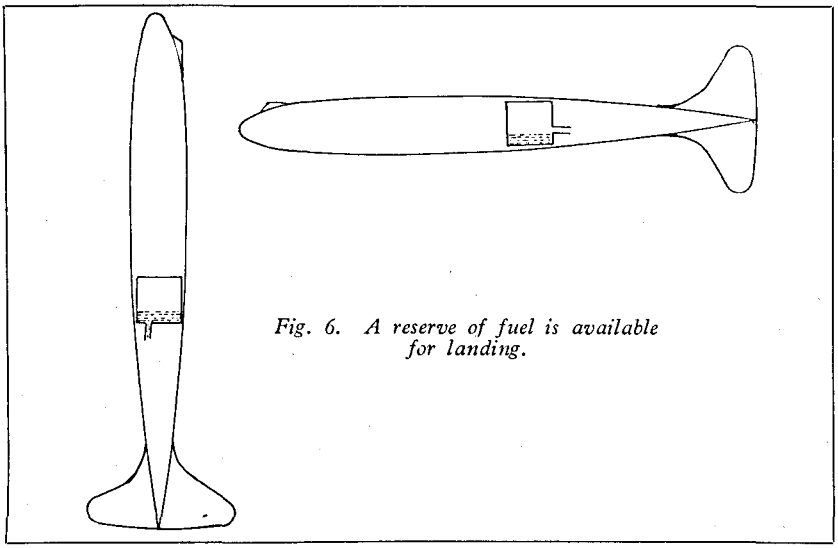

Fig. 6. A reserve of fuel is available for landing.

must come down," and without high efficiency of power transmission, aircraft do not come down so well. That is why most crashes occur.

Zimmerman, whose machine was mentioned by Captain LIPTROT, states that the same propeller can be used for both conditions ; that it should be of low pitch and twist ; that the diameter should be as large as possible without sacrifice of high speed characteristics ; that due to the high disc loading two engines should be used, and that a two-speed gear is desirable for speeds over 250 m.p.h. These statements agree with my own results, excepting that in some cases, for instance the fighter version, two-speed gear is unnecessary. One point regarding Zimmerman's aircraft is that the wing may be bigger than is necessary because of the length of the blades and the distances between the two propellers. Also, most important, it has no positive means of control. Control surfaces in the slipstream were not good enough for helicopters, and are not good enough for helicoplanes. With regard to my high-speed fighter, the propeller efficiency with a single-speed gear is 88 per cent. at 400 m.p.h.

As far as the transition period with the fighter is concerned, there just is not a transition period. The machine would climb vertically at about 400 miles an hour, straight up, and the pilot would simply level off when required by pushing the stick forward, as in any orthodox aircraft. The machine climbs vertically at a considerably higher speed than is required for the wing to give lift.

The transition stage with the transport type shows that this is accomplished smoothly—again simply by the pilot pushing the stick forward. A contra-rotating propeller is necessary to eliminate gyroscopic action, which model tests show would render a machine as suggested by Kurt Tank, unmanageable. His machine represents the old " Camel " in the extreme, I think, with its single rotator, and besides that there is the disturbance over the wing. Both Tank and Zimmerman fail in that they have no positive control. My design is positively controlled by the directable

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jets with stabilising means employed in hovering as on helicopters. In helicoptering the lay-out very closely resembles the Asboth helicopter, a machine which Captain LIPTROT in one of his papers says was stable apart from a conical pendulum motion. This can be rectified by some arrangement similar to that used in the Hiller or Bell helicopters, to control the jets. It is desirable to use propellers of normal type because then we know they are strong enough. There is plenty of data on them and it is just a case of scaling up the size.

Finally, I do not think the buck should be passed to the conventional aircraft firms, because jet propelled aircraft cannot do the job of landing vertically, and will not have the necessary range and endurance. I have not mentioned ram-jets because gas turbines are well developed. We know what they will do, they are reasonably efficient, and I think it best not to jump too far ahead but to use engines which are established. Also, in the fighter version we can use both functions of gas turbines, *i.e.*, either drive the propeller, or use jet thrust.

I think the development of such aircraft should be the co-operative effort of all concerned, and the authorities should be greatly interested in it for the defence of this country and so that we maintain our place in the forefront of aeronautical achievement.

Dr. A. P. Thurston (*Member*) : I have been fascinated very much by the lecture and by everything that has been said. One idea that interested me a great deal is that of putting a rotary affair on some of our big machines, just to test out and see what they would do. I have done that on board ship and it was a most interesting experience. I think much data and information could be obtained very cheaply if you did that.

The other point about this aeroplane-cum-helicopter, or helicoplane or whatever you like to call it, is that modelists have done quite a lot of work which is useful. In one design they had a big propeller taking the torque at one end of their section of elastic and a small propeller at the other end of the elastic, so you see you cut out torque, and then the supporting body to carry the two propellers was fixed, with wings, tail-plane, fins, etc., as on a proper flying machine. So you had a flying machine with two propellers, one at the front and one at the rear, and one much bigger than the other, and when you stood it on its end and the big propeller went up and pulled it up the little one was not doing much of a job, but when you got up the big one cut out and folded up and you simply went merrily along as a flying machine with the little propeller.

I should like to point out that there is a helicopter competition at Langley Airfield on the 24th June this year, and I should like to see everybody here come along with their own pet ideas in the form of models and just show the world what the helicopter boys can do.

Captain Liptrot (Replying to the discussion) : I am delighted to find that a very simple descriptive statement of the convertible without, except in one instance, going into technicalities has started off such a very good discussion. It is quite one of the best we have had for a long time.

Mr. ROWE took me to task because I put forward the small fixed wing idea saying that it was not convertible at all, but he played into my hands by saying that it achieved the same result. That, indeed, was why I included it, because I thought it was germane to the paper if I could say I had achieved the same ends by some other means. Moreover, even though it may not be convertible, it is at any rate variable as regards the operating $\frac{C_T}{\sigma}$ which is the parameter which determines when tip stalling commences. He asked what is the limit to which we can go in putting a very highly loaded wing for high speed flight on a true convertible—not the way I was using it in the fixed wing type. You can go up to almost any extent, I would say, but if you do go to the limit then you will finish up in the uneconomic form where you have a wing big enough for the high speed and a completely separate system to take care of the low speed.

Mr. FITZWILLIAMS said that in putting forward the idea of a small wing I was not suggesting anything new at all because the old autogyros had it. That is perfectly true, but it was put there to give lateral control and they got a free gift in the way of rotor relief but they did not exploit that as a means of improving the aircraft, in the way now suggested indeed they could not do so since the autogyro operates at constant $\frac{C_T}{\sigma}$. I am suggesting the addition of a small wing to a helicopter deliberately to progressively make the rotor operate in the correct condition for the speed at which you are flying. The whole point of the wing addition business is that you choose an operating speed, the minimum speed to do your job, and then you only put on enough wing to keep your blade unstalled at that postulated speed. In certain cases you will get benefits well above that.

In one of the design studies which I have made I was able to achieve what I have never seen anywhere before, a helicopter with every characteristic required, which was only given enough wing to keep it unstalled at a postulated flying speed of 145 miles an hour. Well, it kept unstalled up to 200 miles an hour, at which I had the one thing I have never had before—I achieved all my limitations of power input, tip stalling and compressibility at the same speed.

Another immensely important point is the power consideration. At your operating speed you must not be taking more from your engine than will permit the engine to have long life in between overhauls, and it is in those ways, in giving you the operating speed which you want without tip stalling at a power output which you want, which makes a small wing so very very attractive.

Mr. SHAPIRO, I think, agreed in the main with my own arguments, and he certainly agrees with me that the Kurt Tank type of convertible is something which must be explored in detail if we want very very high operating speeds with the power of vertical take-off and climb.

Mr. HAFNER did not agree with me when I said that the gyrodyne can exploit the reduction of $\frac{C_T}{\sigma}$ better than the conventional helicopter. I know what he was arguing, but surely this is the point : if you reduce the axial flow through the disc by not tilting the disc so far forward then your collective pitch angle is smaller than before and therefore you can go further in the direction of increased tip speed ratio before you hit tip stalling. I think he was arguing that you could twist the blade, which is perfectly true up to a point, but that cannot be taken too far, otherwise you destroy the auto-rotational characteristics upon which you are dependent for your forced landing, and the benefits which you get from twisting the blade are not so very very great. The overall increase in efficiency of a rotor from the twisting and tapering of the blade is only of the order of 4 per cent. after all, so I think it is true to say that the gyrodyne can benefit more from the exploitation of reduced $\frac{C_T}{\sigma}$ by small stub wings than the other type of helicopter.

My main critic is, of course, Mr. ANDERSON, and I do not think that this is the time or the place to go into a detailed analysis of all the things he said, but I think I must point out, as a lot of it was directed at me personally, that at the time he first brought it to me either he was not clear or I was much more dense than usual, because he most certainly did not put it forward to me as exploiting the side forces experienced by a yawed propeller, and I must still insist that in that type of helicopter where you rotate through 90 degrees, the rotor must be primarily a propeller and therefore you cannot develop high hovering lift. It is fundamentally true that to develop high lift you must have, I will say, a relatively big diamater rotor at low revs., and for the high speed flight condition you must have a relatively small propeller.

Mr. ANDERSON also said that putting stub wings under a rotor in the form I suggested was going to destroy the whole thing. That is not true. The amount of stub wing which is necessary to keep the blades unstalled is so small that the only influence is to reduce the lift of the rotor for the same horse power by something of the order of only 2 to 2½ per cent. It is not appreciable, and the benefits which you get at the high speed end of the range much more than counter-balance that small loss. As Mr. ANDERSON now puts his proposal forward as an exploitation of the use of the side force on a propeller, as I have said before I am with him—it is something to be developed—but it was never put forward to me by him in that form on the previous occasion.

There are other difficulties in the vertical take-off type ; it may be very useful for military purposes, where you want high speeds, but I am sure it is not going to be used for civil transport. The mere fact of rotating the whole aeroplane through 90 degrees means that you either take off with you passengers lying on their backs with their feet up or you put them on a swivel chair, and a fare-paying passenger does not want to go on a fair ground and have a swing, and if you do put a swivel chair there in such a way that you have adequate clearance both in the vertical and horizontal position you are going to virtually double the length of your fuselage, and then up goes your cost and your overheads and it becomes uneconomical. I think that is all I need to say.

The Chairman : As you are aware, we are privileged—indeed we are honoured this afternoon to see Major BULMAN amongst us. This is, I believe, his first experience of a meeting of the Helicopter Association and I now invite him to give us his views on this question of the convertible aircraft, an invitation which I hope he will accept.

Major G. P. Bulman (*President, Royal Aeronautical Society*) : I came here this afternoon to show, as far as I could personally, the interest and sympathy which the old Society has for your Association. Secondly, I should apologise for the fact that, owing to a misunderstanding on my part, the publicity given to this lecture in the Society was far less and far later than I would have liked, and that, I am afraid, is why there is not a bigger number of the members of our Society present.

At the same time the fact that you people come along on a Saturday afternoon and spend the whole time discussing technical affairs is a great tribute—today, especially, being St. Patrick's Day and also with an interesting competing event at Twickenham. But having come, as I have described, I found myself extraordinarily interested both in the paper and the discussion.

For many years—I think over thirty—I have regarded my old friend Captain LIPTROT as rather like a man who is very stalwart and insists on the efficacy of a very cold bath, and now I suddenly find that he is showing symptoms of suggesting that you might add a little hot water tap somewhere, just to take the chill off. I used to think that he was a bit " loopy," so to speak, when he thought that one ought to be content with something that just goes round and anything fixed on it was almost sacrilegious even to mention. I put it on a par with some of my dear friends the airship people—the balloonatics—who used to think the whole object of a man's life was to float about with a gas-bag over him and some sort of basket under him, but I regard it a great wisdom on his part now to feel that there may be something which you can add on to the thing which goes round to produce something more useful to the world. It perhaps may not be quite so interesting but it is fundamentally more useful. I admire the way in which he offers you this and that at the expense of something else—in other words he is not being, perhaps, as dogmatic now as he used to be, and that is a great step in the direction of wisdom

In the matter of convertibility the word seems to conjure up to me an interpretation in finance which we used to hear a lot about. It was always a matter of great complication, and rather hot feeling sometimes, and in the end never did enybody any good. Whether that applies to this particular aspect of convertibility I do not know. I was reminded of the many times when I was mixed up with engine affairs and of the number of people who said to me, " Cannot you combine the long-range virtues of the diesel engine with the much greater powers of the petrol engine, and make it into one engine, and then you can convert from one into the other by pulling a lever ? " Well, that lever was a bit complicated, and so I would feel to be any marked degree of convertibility on the going round as opposed to the flat thing.

I am glad that Captain LIPTROT felt so keenly on this matter of the passengers. I was wondering myself what happened when you changed from the vertical to the horizontal, and he described it very adequately. I am one of those people who always prefer to sit with my back to the engine—when flying, at any rate—and I pictured myself sort of hanging down and then shooting up, and I did not feel it would be very comfortable. I may say I am taking a little bit of personal interest in the helicopter in that for a certain event not very far distant I have to use one, with my wife, to arrive somewhere.

I do thank you for giving me this opportunity again of wishing the Helicopter Association all success, as I am sure it will achieve through its own efforts. May I say I regard this Association rather as an advance party of the Pioneers—a sort of Chindit force which is pushed out into the blue with only its own resources, cut off completely although it has good friends behind it, but pioneering something in the face of great difficulties and in the process getting clear minds and, when they come back, giving great inspiration to those who stayed behind.

The Chairman : We do feel that in the Royal Aeronautical Society we have a very friendly and an almost avuncular personality, or body, and I know from our past experience that we can look to the Society in the future for all the support that we shall need.

One important thing we must keep in mind about this convertaplane proposition, I think, is the advance that has been made and the work that has been done in America in quite recent times. I did mention at the beginning that some seventeen firms have been engaged upon research of this kind, and there is a considerable sum of money available in America to back up that effort.

That concludes our meeting, and nothing now remains except to ask you to extend thanks to Captain LIPTROT for this most interesting paper, and I think the best form of showing your appreciation is in our usual way. (*Acclamation*).

(*The proceedings then terminated*).