Evening Session

When the meeting resumed after tea the CHAIRMAN invited Members to take part in open discussion, and called upon Dr J A J BENNETT to open the proceedings —

Dr J A J Bennett (*Founder Member—Fairey Aviation Company Ltd*) We have listened to-day to a succession of authoritative papers on the theoretical and practical problems of rotor blades and I should like to congratulate the authors for providing us with so much food for thought Perhaps I might mention a few points which I consider to be of outstanding interest

(1) *Vulnerability to fatigue* I think I am right in saying that a primary obstacle to the development of helicopters in this country has been their vulnerability to fatigue This has caused attention to be directed to the design and construction of rotor blades mainly in regard to their airworthiness There is first of all the consideration of the factors which promote a dynamic simplification of stress fluctuation and, secondly, if it is not possible to avoid these factors altogether, we have to make sure that the blade construction is as insensitive as possible to fatigue conditions

2 *Drag hinge excitation* It appears to me that the introduction of a drag hinge in the early days of rotary wing development was a mistake The periodic bending moments caused by the flapping motion of the blades might have been kept within safe limits by ensuring that the dissymetry of forward flight was compensated by cyclic feathering Thus the tip-path plane could have been maintained substantially at right angles to the mechanical axis of the hub The possibility of stress amplification by the self-excited motion of a drag hinge need never have existed Of course, unstable motion of the drag hinge is suppressed under normal operating conditions by a limited amount of frictional or hydraulic damping, but it is a potential amplifier under conditions of abnormal excitation

3 *Critical effects of mechanical transmissions* A feature of the mechanically-powered helicopter is that it can be most vulnerable to stress fluctuations of high amplitude which may be excited at or near critical speeds of the rotary systems due to the flexibility of the mechanical components The absence of mechanical transmission in a jet-powered helicopter, therefore, should minimise the vulnerability of fatigue

Another risk to which rotor blades are exposed is the possible occurrence of extremely high transient stresses under abnormal operating conditions One such case is a sudden cut in rotor power A jet-powered rotor blade must be designed to withstand a sudden failure of the jet thrust and a mechanically-powered helicopter must withstand the subsequent bending oscillation of the blade when the driving force at the drag hinge is suddenly removed This force may be very large in mechanically-driven rotors when the drag hinge is located near the hub axis It is at a minimum when the blade is driven by a tip-located jet

4 *Blade twist* With regard to blade shape, helicopters with propulsive powered-rotors can reduce their inherent tendency to operate close to the periodic blade-tip stall by having a built-in twist as in a propeller blade On the other hand, the accentuated inboard stalling of the autorotative rotor is reduced by a built-in twist in the opposite sense Helicopters operating on the gyrodyne principle, with their tip-path plane nearly level in forward flight, require no twist as they avoid the operating limitations of the two extremes However, twist and taper do not appear to be so effective in practice as on paper, probably because the effective length of the blade is relatively short

5 *Torsional stiffness* The combination of torque and upward bending causes a torsionally-flexible blade to move in a relatively uncontrolled manner in forward flight Although this uncontrolled motion of the blade tip should be greatly reduced in tip-driven rotors, the mass of the jet unit helping to keep the blade straight and the absence of torque reducing the torsion induced by bending, perhaps it would be better if the blade could be cyclically feathered from the tip instead of from the blade root In other words, the blades should not only be tip-driven but tip-controlled The blades would be less sensitive to torsional flexibility, shape and stiffness of profile, and it would be unnecessary to ensure that the blade pitching moments were substantially zero

Tracking in flight with cat's eye reflectors at the blade tip and using an Aldis lamp was found to be most effective on the GYRODYNE With regard to the method used by Bristol, of balancing blade pitching moments to eliminate stick shake, I think that the spirit of Johann Sebastian Bach must have made a prior visit to Bridgeport, Conn

Mr J Wotton (*Member—Percival Aircraft Ltd*) The papers to which we have listened to-day make it very clear that generalization of the subject in its entirety is not, and perhaps never will be, possible, except in the broadest of terms

Whilst an ever increasing amount of reliable data is being steadily built up, new and attractive fields of exploration and possible lines of investigation continue to appear calling for new conceptions of rotor behaviour and for improved production methods

Rotors having two or three blades now take their place with those having four or even five blades and the simplicity of the familiar two bladed see-saw type is likely to be seen in a modified form in rotors having three or more blades

This arrangement is most readily adapted to rotors other than shaft driven and the freely tilting but otherwise rigid rotor is worthy of attention, for, whilst complicating mathematical evaluation, production and maintenance are very considerably improved

The advents of jet driven rotors has done little to simplify the task of the designer, who now finds himself confronted by an entirely new set of problems

It is clear that fundamental differences separate the requirements of shaft-driven, normally operated tip-jet and pressure jet rotors

High and low pressure jet systems also call for individual treatment and the blade sections themselves will differ to a marked degree for the conditions in which they will operate are entirely dissimilar In the low pressure system a mixture of hot gases and cold air is conveyed from gas generators located within the fuselage through the rotor head to the blade tips

It can be shown that in order to obtain good efficiency the optimum velocity of gas flow and the permissible heat loss during its passage through the blades is fairly well defined, whilst the expansion ratio between generator and tip jet is determined by consideration of ducting losses and the propulsive efficiency of the jet

A lowering of pressure and an increase of mass flow in the system in order to obtain maximum propulsive efficiency is met by an increase in blade solidity and power requirements

It is, therefore, essential that the largest possible duct area for a given blade chord be obtained

This suggests the use of a thick-sectioned blade such as one of the high thickness/chord ratio N A C A sections Such a choice, of course, introduces manufacturing problems in maintaining an accuracy which will ensure the required laminar flow, for without it the drag on any thick section becomes quite prohibitive The design must provide internal gas-carrying ducts, whose pressurisation will not affect the external contour of the blade, which can accommodate the inevitable differential expansion and can be satisfactorily insulated in order to avoid loss of heat and a reduction in overall thermal efficiency

The preservation of accurate contours is difficult, but the use of a thick skin supported on accurately formed ribs may provide a solution The employment of the latest skin forming and arc welding techniques can be used to ensure a ripple-free high stress bearing construction

The ducts in such a blade would carry only their own centrifugal load, being anchored at the root and left free to expand lengthwise along the blade The temperature range over which this method can operate is determined only by insulation limitations

The opposite method, in which the duct is the stress bearing member, has already been described, but this has a temperature limitation of around 200°C as the main blade structure is directly affected

It is significant that any pressure jet system must have some heat loss to the outer skin and so should be free from icing troubles

An advantage in the case of the low pressure non-tip burning system is the absence of electrical conductors and fuel lines in the rotor head and blades

A parallel blade plan form of constant section will in general be found most suitable in any of the jet systems, but it is questionable if for any helicopter the added cost of tapered blades is fully met by the few per cent increase in efficiency which is obtained Twist, of course, is readily introduced without complication or additional expense

Close attention should be given to the economics of blade production and hence the design chosen must be cheap in terms of flying time, *i e*, to be either long-lived or inexpensive to replace Blade maintenance and renewal can easily become one of the major items in helicopter operation, and the designer should decide how much over-elaboration of design or finish, in order to improve efficiency, is justified

For instance a set of present-day blades for a 50 ft diameter rotor may cost £3,000 or even more At a replacement life of 1,000 hours this represents a flying cost of £3 an hour Such a rotor would probably be driven by a 500 h p engine whose normal overall fuel consumption would not exceed 30 gallons per hour at a cost of £6, or only twice the cost of blade replacement If the blade cost can be halved, or alternatively if its life can be doubled, the replacement cost compared to fuel cost falls from 50 to 25 per cent Hence it becomes apparent that too much finess in the quest of flight efficiency may constitute a liability and not an asset, for quite a considerable increase in production costs, when assessed in terms of fuel economy, may result in only a three or four per cent improvement

It would seem preferable for arrangements to be made in all designs whereby adequate tuning of the rotor can be carried out along the lines suggested in the excellent paper on that subject given by Mr TURNER The improvement in smooth rotor running obtainable by careful tuning, with its obvious repercussions in blade fatigue, can perhaps best be appreciated by those who have been privileged to fly in the Bristol machine

For any but the smallest rotors, all-metal blade construction has obvious advantages, and for certain purposes metal blades are, of course, imperative

It is interesting to note that of the firms at present building or designing helicopters in this country, no two are working on identical rotor blade design This is not merely due to a desire to be " different," but as a result of the pursuit of a number of different lines of investigation

There is as yet no indication that finality in helicopter design is in sight either in configuration or in methods of rotor drive, but it is quite certain that the subject which interests us to-day will be forever with us, and there is no doubt that in this field we can be sure to continue to find variety if not always entertainment for many years to come

Mr K Watson (*Founder Member—Saunders-Roe Ltd*) I would like to begin by congratulating the Council for their wisdom in the choice of papers which we have been privileged to hear to-day

This morning we heard what Prof OWEN and Mr SQUIRE had to say about the theoretical approach and I must say that after listening to them I was left in a state of animated suspension This afternoon we heard a great deal about the more practical aspect of the business , Mr HODGESS with his jet propelled all-metal rotor blade, Mr FITZWILLIAMS with his bonded metal rotor blade construction, then we heard what Mr MORRIS had to say about his wooden type of construction and finally Mr KING with his improved bonding methods But the cunning bit about it all was that after hearing why and how, it was appropriate that Mr TURNER should tell us how to overcome the difficulties that we had already landed ourselves in I thought that very clever

Dealing with the discussion this afternoon, I feel it my duty to explain that my past association with the helicopter and its problems begin as a rule well down the line and finish at that point and no further, where the rotor blades begin I am glad to say, however, that after listening to what has been said, I at least have been greatly enlightened and feel sufficiently armed to at least argue with the learned gentlemen who operate beyond the dreaded line

I have been extremely interested in the various methods of construction put forward and the methods employed in overcoming the difficulties experienced On the other hand, I am perturbed when I hear reference to accuracies of 1/1000th of an inch being required for final setting on a rotor blade If such accuracy is found to be an absolute " must," then I feel that the problem of rotor blade construction will demand an entirely new approach It will obviously take one away from the established practice of fabrication to one of real precision engineering

I was intrigued by what Mr TURNER had to say about tuning the rotor and could not help feeling that, in view of the magnificient approach to this problem and the time and trouble involved in solving it, it might possibly be easier to tune the rotor first and then construct it afterwards (*Laughter*)

On the other hand, does Mr TURNER consider the problem of delicate tuning inevitable when associated with high tip speeds , if so, what are his views on the approach to still higher tip speeds ?

I was interested in what Mr HODGESS had to say about the construction of the tip-driven rotor blade. I note that he favours the conventional tubular spar, rib and skin construction. There is one point I should like to hear from him on and that is how he proposes to deal with the possibility of loosening of the friction type rib clamp which might possibly be stretched due to temperature differences between spar and rib if not properly pre-tensioned.

Another point is, what are his views on the almost inevitable possibility of fretting or surface abrasion between the section overlaps due to the flexing of the blades?

On the one hand we have heard a strong recommendation for the rigid accurate trailing edge, while on the other we have seen two examples of sectional construction involving a slit trailing edge. What are the views of the exponents; which is the correct approach?

Two further questions which I would like to put to Mr FITZWILLIAMS: (1) Was the adjustable tip weight shown on the bonded metal blade for dynamic balance only, or did it contribute to both dynamic and quarter chord balance? (2) Is the pressure required for pressing the surface together during bonding applied mechanically or by pressure in an autoclave?

Mr Shapiro (*Founder Member—Consultant*): It has been said that the best a modern propeller can do, compared with two planks of wood set at the correct angle, is an improvement of efficiency by about five or ten, hardly ever fifteen, per cent. I think one reason why these two planks of wood are no good for a helicopter is that the same fifteen per cent. represents so much in terms of what the helicopter really does. When we discuss the improvement which a well designed rotor produces we should express it in terms of the pay-load. These six to eight per cent. which are gained through taper and twist represent something like 25 to 30 per cent. of the pay-load.

Taper is fully justified therefore to increase the load which we can carry, but it is also justified because it allows us to obtain better average strength factors, particularly in large rotors.

The significance of twist was very well put, but I would like to point out that elastic twist is a factor which makes rotor testing and the correlation of theory and experiment difficult. The twist that matters is, of course, the actual twist in operation and not the built-in twist alone.

I would like to amplify with a few remarks what Mr SQUIRE has said about compressibility. When we discuss rotor aerodynamics we should always turn to the drag and lift functions. In other words, the C_D and C_L as functions of the aerodynamic incidence.

When we design a rotor for flight under certain conditions we must determine the range of incidences in which a representative section works. What matters is the drag coefficient for the whole range of incidences; not the area under the drag curve, but something which approaches it. We have to associate a weighting function with each incidence and then get a really precise quantitative method of evaluating sections in this way.

Taking into account compressibility effects we get a family of curves. First we have the basic curve at very low Mach numbers. There is a range of Mach numbers for which there is substantially no departure from the basic curve. Then we observe an increased rise in drag at high incidences. With a symmetrical section of about 12 per cent. thickness, we start departing from the basic curve at a Mach number of ·5 to ·6. Finally, somewhere around ·7 to ·75, the drag begins to rise at the lower incidence. We should distinguish between "drag divergence" Mach numbers at high and at low incidences. So long as we have only drag divergence at high incidence the rotor will hardly be affected, but when we get to divergence at low incidence it will. The low incidence drag divergence defines the limiting Mach number at the advancing tip.

One or two points on the subject of blade construction. A rotor blade will always constitute an assembly of dissimilar components. We have basically a skin which is a sheet component; a spar which is a tubular component; and a root fitting which is essentially a machined component. The combination of all these will always demand a great deal of ingenuity, and it is because of this that we have variety in rotor blade design, and we shall continue to have it because there is here an inherent and essential difficulty which we have to overcome.

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Mr R Hafner I have had my say this morning and I ask your indulgence now for only a few more words

Mr HODGESS' discussion of the problems in connection with the tip-driven blade interested me very much, and there is one question I should like to put to him With a rotor blade which carries air along its spar you have to consider the loading on the blade in the plane of rotation to the mass of this radially flowing air (Mr HAFNER drew a blade on the board and illustrated his remarks by the aid of it)

We have here a very high rate of radial flow whilst the blade is rotating and the resultant Coriolis acceleration is considerable It strikes me that the dynamic load from this acceleration is considerable and I wonder if it has been calculated ?

Lt -Col Hodgess (*in reply*) I should like first to answer the questions put by Mr WATSON His first question was what would happen if the rib clip wedges tended to slip A very similar system of construction was used in the Gyrodyne and there was not a single instance of any friction clip having moved from its original position

With regard to chafing of the sections, the differential loading between one element and another is small and, in this case, one element fits over another like the lid of a biscuit tin It is just sufficient to keep the form of the open end of the element

What we have heard about trailing edge deflections in rotor blades is rather disconcerting The construction which I have described does not have a free trailing edge because each of the trailing edge blocks dovetails into the other, forming in fact a continuous trailing edge, though not a continuous strip

With regard to Mr HAFNER'S question, the acceleration of the air is an aerodynamic problem which I ask Mr Stepan to answer

Mr A Stepan (*Member—Fairey Aviation Co Ltd*) In reply to Mr HAFNER'S question The Coriolis force due to the internal air flow in a pressure jet system amounts usually to only a few pounds per foot length of the blade and absorbs not more than a few per cent of the available horsepower Thus, in the pressure jet system, the bending moment on the blade is not appreciably changed but, in a helicopter which is powered only by a very high mass flow of air, the Coriolis loading is more important

The horsepower absorbed by the Coriolis force is not lost, however, as it is recuperated from the jet due to the increased pressure of the air

Mr K W Turner (*in reply*) I thank Mr Wotton for his kind comments on the effects of rotor tuning on Sycamore passenger comfort In reply to his query about the one-thousandth of an inch business, I must emphasize that this accuracy in blade profile is required only in matching the blades, and not collectively as it were for the rotor as a whole That is to say, distortions of this order may cause fuselage or control shake , but the behaviour of the aircraft in respects other than vibrational will not be seriously affected until the distortion amounts to hundredths rather than thousandths of an inch

Mr WATSON has enquired about the effect of high tip speeds on rotor tuning —or, to express the question in another form of which I am sure Dr BENNETT will approve "Will high Mach numbers require high Bach numbers ?" In this matter I feel we can only wait and see It is I think no secret that fast fixed-wing aeroplanes are finding themselves very sensitive to what happens at the trailing edge Similar or worse trouble may well be encountered by helicopters if their blades are ever designed to operate at near-sonic speed

Mr Fitzwilliams (in reply to Mr WATSON)

(1) Weight fitted to the tip of our metal blades is movable chordwise primarily to provide means for adjusting the pitching moment characteristics of the blade This is, however, only another way of saying that the weight is used to counterbalance discrepancies in the chordwise balance of the blade, since when all blades are adjusted to have the same chordwise balance, this apsect of pitching moment characteristics can be considered to be standardised

(2) The pressure required for pressing the surfaces together during bonding is applied mechanically by means of clamps fitted with pre-set compression springs

In closing the meeting the CHAIRMAN remarked on the high quality of the papers presented and on the high level maintained throughout the discussion He felt that it would be generally agreed that the meeting had been a success, and on behalf of the Association he thanked the Speakers and asked Members to show their appreciation in the usual manner

(A vote of thanks was accorded with enthusiasm and the meeting closed)

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THE HELICOPTER ASSOCIATION OF GREAT BRITAIN

Londonderry House, 19 Park Lane, London, W 1

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Founder Members shall comprise every person who on August 31st, 1946, was on the Register as a properly qualified Member of the Association

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Fully qualified Members shall comprise every person who was on the register as a Member of the Association on the date of adoption of these Rules by the Association, and every person thereafter elected or transferred into the grade of Member

Every candidate for election into the grade of Member shall possess the following qualifications —

(a) He shall be twenty-five years of age or over

(b) He shall be actively engaged at the time of his application for election in the design or in the production or operation of such works as are comprised within the science of rotating wing aircraft , *or* in the application to rotating wing problems of special branches of science, mathematics or engineering

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(c) He shall hold a professional pilot's licence issued by a recognised authority or be an officially approved Test Pilot or a fully qualified Service pilot, *and* with these qualifications, have been actively engaged in flying rotating wing aircraft for a period in excess of two years

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TITLES should be as brief as consistent with clarity, and in many cases the value of a paper is enhanced by a short SUMMARY

CHARTS, GRAPHS and DRAWINGS should be, if possible, in Indian ink on white board or strong paper, with detail and essential lettering large enough to be clearly legible after reduction if necessary

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