Discussion

Mr W A P Fisher (*Royal Aircraft Establishment, Farnborough*) I have listened with the greatest interest to both these papers by Mr BRENNAN and Mr HAFNER and would like to start by paying a tribute to the concentrated effort and evidence of practical skill and ingenuity which has been shown by their firms in carrying out all flying measurements and ground testing I think the utmost use should be made of the records thus obtained

I was also very deeply impressed by the great variety of the separate and individual *ad hoc* tests which Mr Hafner mentioned, and how, in the case of the dynamic tests, they were related to his theoretical investigation on the resonance characteristics in controls, transmission and blades

In the very limited time I have available I propose to discuss the principles, rather than the techniques of this problem, and particularly to refer to the fatigue aspect Fatigue in helicopters, being due to other factors than those affecting fixed wing aircraft, has had to be treated in a different manner In fixed wing aircraft the loads which can lead to failure of the main structure accumulate relatively slowly and the main consideration for safety in civil transport aeroplanes is the resistance to a great number of atmospheric gusts It would be most inexcusable if such an aircraft were to break up in less than 3,000 hours' flying In helicopters, as we have seen, the critical fluctuating loads are those which are inherent in this form of flight These continuous fluctuations produce millions of cycles in a matter of 100 or so flying hours

In the case of the Skeeter, alternations of 3 times rotor frequency were present throughout the flight range, but were not normally present in ground runs

Mr Brennan says " I should emphasise that the engine vibrations, which are of a high frequency and without a doubt the start of fatigue failure are larger on the ground than in the air " That, perhaps, is slightly begging the question because the fatigue effect surely will be due to the combination of the 3 times rotor vibration and the more rapid engine order vibrations, as was seen in some of his records, where the amplitude of the former is the higher and therefore the more significant Thus, the important thing is whether or not these three times rotor oscillations are in general of significant magnitude in the transmission

I was very glad that Mr Hafner emphasised the point that the conditions in ground running must be at least as severe as those in flight I heartily endorse that view , in fact, I think that from a " safety in fatigue " aspect it is advisable, where possible, to make the ground conditions more severe, to some definite extent The conclusions to be drawn from the test are then much more valid and certain One reason for this is, of course, the phenomenon of scatter in fatigue In making strength tests in fixed wing airframes, allowance is made for a variation of 20 per cent by applying a test load 1 2 times the design figure In fatigue testing scatter in endurance can be of the order of 2 1 under high alternating load, but it can increase up to 50 1 or more in the region of the endurance limit Thus in a test employing simulated flight loads if a particular assembly withstands x hours without failure it is quite conceivable that a similar one can fail in x/10 hours when x/10 represents an endurance of the order of 1,000,000 cycles Thus, if clearance for flight is based on half ground running time scatter might be covered in the early stages by the factor 2 but it is not safe to regard it as covered thereafter The only safe procedure is to apply a small factor on the peak alternating load and thus provide against scatter without serious effects on the components

The idea of testing to factored repeated loads is not a new one For example, I should say you would be unlikely to get a clearance document for mine shaft machinery by applying the actual working load for, say, a million times Engineers would require many applications of a higher load I should say the same would apply to a simple crane hook used in the dockyards Regarding the helicopter as a form of " sky hook," I think we should apply the same rule

There is also a possibility that fatigue can result from increased vibration due to the development of wear Aircraft engine experience is some guide on how much wear can be allowed Doubtless with helicopters the usual procedure will be adopted, *i e* , gradually extending overhaul periods in the light of experience

Endurance testing for functional and mechanical reliability is not the same thing as endurance testing for fatigue I think everyone is agreed that for checking functional and mechanical reliability one cannot do without this testing of simulated runs of the engine, as described by Mr Brennan The rotors and their associated parts are as vital to the helicopter as the wings are to the aeroplane If an engine fails in a fixed wing aircraft this is not by any means necessarily catastrophic If you have several engines and one packs up you just carry on If you have only one engine and that packs up you still have a very good chance of getting down again That happened once to me, in fact, flying at 2,000 feet The pilot made an excellent landing in a field and I am here to-night In helicopters, one failure of the rotor, the blades, or those parts directly associated would be catastrophic I think we must be more stringent in our fatigue strength requirements for these vital parts than we would be for an engine

Lt -Col F L Hodgess (*Member—The Fairey Aviation Co Ltd*) Most of us here have been privileged to listen to Mr HAFNER'S previous lectures and to-night he has certainly maintained the very high standard to which we are accustomed It is also encouraging and stimulating to the Industry to receive a lecture from a comparatively new member , nevertheless Mr BRENNAN is to be congratulated on his paper in which he has shown us some of the very real problems connected with the strain gauging of Helicopters Unfortunately, I did not receive an advance copy of Mr Hafner's paper in time to pick the bones out of it, so I am afraid Mr Brennan will have to face most of my fire

Mr Brennan stated that he obtained greater fluctuating loads on the ground than he did in flight and has therefore assumed that the stress enveloped from a fatigue point of view is covered To my mind the whole argument rests on whether the stresses produced on the ground are representative of those in flight Was the Skeeter standing on its normal undercarriage and tyres when tethered ? If so the natural frequency of the machine would be altered and many modes of vibration from first rotor order onwards could be either increased or decreased, in fact the whole resonant pattern could be so altered as to be no longer representative Most of us, who, perhaps like Mr Hafner have been a long time in the game have experienced the change which can take place in the behaviour of a helicopter when free, and when tethered to pickets in the ground

One photograph shows slip rings of rather large diameter, and at the full speed of the rotor the peripheral speed might be of the order of 900 to 1,000 ft per minute, and as the slip rings and brushes are also subjected to atmospheric conditions it would appear very difficult to avoid picking up a lot of hash in the signals Has Mr Brennan tried using mercury pick-ups ? These have been used successfully by engine manufacturers when strain gauging turbine blades both for ground running and under flight conditions When used in conjunction with a telemetering unit to transmit the signals to a ground station the amount of airborne equipment can be correspondingly reduced

Mr FISHER has mentioned a point which I was going to raise, namely the scatter which is normal to all strain gauging operations In order to get anything like an S/N curve, many hundreds of tests would be necessary which is clearly impossible when strain gauging a complete rotor system, nevertheless I am reminded of a very enjoyable visit the Association paid to the de Havilland Propeller Company a year or so ago, and I for one was very impressed with the amazing number of repetitive tests made by this Company in order to ensure a complete fatigue envelope for the particular unit being investigated

Referring to Mr Hafner's paper I note that most of the ground running was done with the aircraft suspended from a grantry, and this would appear to confirm my earlier remarks

Although the Bristol Tower is a valuable piece of equipment for testing a single rotor I would think there must be many problems associated with tandem rotors which would require an even more elaborate set-up, particularly when investigating the interference of one rotor with the other

Mr J S Shapiro (*Founder Member—Consultant*) I fear that the lecturers and some of the speakers in the discussion have largely avoided the issue which is the main subject of the meeting Both lecturers had extremely interesting, valuable and novel information to communicate, and I believe that if they have not said very much about simulation, it is not their fault but the fault of the subject

Simulation is an artificial method largely intended for endurance testing We have no cause to take its usefulness for granted No one will doubt that simulation is difficult but I am slowly coming to the conclusion that it is not really worthwhile

To establish simulation as a valuable method of endurance testing, it has to be proved that we can reproduce the essential stress pattern encountered in the most critical states of flight, that by making use of such reproduction we can pursue endurance testing more safely, and/or more economically than in direct operation or by component rig tests, and finally that our ideas on what is the most critical stress pattern in operation are valid Without completing the whole chain of reasoning, of which each link requires thorough experimental verification, simulation remains another gambit in the game of guessing It may nevertheless be most valuable because experience with simulation, however imperfect and uncertain, may enrich the designer s imagination, make him alive to dangers he has hitherto neglected Even so, simulation is a rather expensive method of stimulation

On the first point the lectures show that simulation cannot reproduce the stress pattern experienced in flight There was no discussion on the question whether simulation tests are more economical and practical than other tests I should like to draw attention to the third point in the plea for simulation Do we know which stress pattern is the most critical ? This knowledge implies that we assume real machines to behave in accordance with certain mental or laboratory models Fatigue failures are only another instance of a particular model of a destruction process

The real core of the airworthiness problem is that the behaviour of a machine in reality is always more complex than that of any model we conceive in advance In other words, it is the dangers we have not thought of in the past which are the really difficult ones to guard against Simulation can at best deal with the dangers we have thought of I suspect that in most cases there are cheaper methods of doing so, such as component rig tests

I believe that maximum efforts should be devoted to the task of finding the best means of provoking, discovering, and neutralising the unknown dangers with the best economy and maximum of safety It seems to me that the ability of the helicopter to fly very near the ground is one avenue towards this goal and one not sufficiently made use of

Mr J Keri Williams (*Member—Air Registration Board*) ° I propose to deal with the fatigue aspect only which is one of the most important structural problems we have to face in aircraft design at the present time and especially in the design of helicopters I wish to congratulate both contributors for their papers indicating the great effort which their respective firms are making to solve this problem on their particular helicopters

The fatigue problem on helicopters should be regarded as being of a more serious nature than on fixed wing aircraft for two reasons The first is that on aeroplanes we have a reasonably clear idea of the magnitude and frequency of the gust loads experienced by a wing structure and it is not difficult to subject spar boom specimens to fluctuating tensile loads in the laboratory On helicopters, however, it is extremely difficult

(*a*) To realise the full extent of the problem, what is the nature and magnitude of the fluctuating loads, and how many parts are vitally affected ?

(*b*) To simulate these stresses by ground testing

There is a vital need to distinguish between the helicopter as a military vehicle where a certain percentage loss due to various causes, whether operational or structural, etc , is acceptable, and the helicopter designed as a passenger-carrying vehicle for hire and reward on scheduled routes where structural failure due to fatigue or other cause is utterly unacceptable It may be unfortunate that in this country helicopters are developed simultaneously for both roles, because production for the military cause may be handicapped by too severe standards, but on the other hand, the standard of testing may not be good enough for civil helicopters Here there is need for the maximum co-operation between all concerned because there is great sympathy with designers to prove the fatigue airworthiness of their helicopters, but please have reciprocal sympathy for the Airworthiness Authority which has to decide at a certain stage in the testing that the helicopter is now O K when the problem is such a complex one

Simulation of flight loads by ground testing methods may be composed of laboratory testing of components, rotor tower tests and the rig testing of the complete helicopter It is very doubtful whether the principle of the attempted simulation of flight loads by ground testing can do more than just help in the design development of the helicopter because it cannot provide an absolute answer on the safety aspect of the machine This is necessarily so because of the grave errors which can be introduced in the intermediate stages of the translation of flight loads into ground test loads (*a*) In the measurement of flight loads Here we are limited by the means of measurement, *i e*, strain gauging with its attendant errors and the accessibility of components For example, on rotor blades, expecially when a composite wooden construction is used, it is essential that the flight strains be measured not only on the outer surfaces but also inside the blades In addition, on complicated parts of the rotor head, such as bolted steel fittings, it is not possible even to attempt to measure the strains

(*b*) In subjecting the ground test specimens to the best estimates of flight loads, similar additional errors as in (*a*) will again arise

(*c*) For the ground testing to be completed in a reasonable time it is necessary to decide on one level of test loading to cover the various flight conditions, and this involves a cumulative assessment of the effect of loads at various stress levels This problem in itself is complex as anyone who has studied the fatigue literature will substantiate

There will always remain the suspicion that the loads in the critical parts are not being simulated, due perhaps to the impossibility of detecting these parts It does seem, therefore, that the simulation of flight loads in operation should be done by the actual flying of a " slave " machine, but this obvious method seems to be unacceptable to all concerned

Thus the general conclusion from the civil aspect is that we are at present in rather a gloomy frame of mind It would be a tragedy if the future development of the helicopter were retarded by premature failures at an early stage due to a too optimistic assessment of the results of simulated flight loads by ground testing

Dr H Roberts (*Founder Member—The Fairey Aviation Co , Ltd*) We have heard quite a lot about strain gauging, but I am not at all clear that the loads we are trying to simulate and measure on the ground bear much relation to the actual flight loads which occur It is very much a case of which comes first, the chicken or the egg The loads that occur are not known until the flight tests are completed, but flight tests cannot safely be started until the ground tests have been adequately undertaken

We generally start by putting on perfectly ordinary loads, and it is usually not till long afterwards that the results are available in a form from which logical conclusions can be drawn On what possible basis can these loads be selected ? It seems to me that unless you çan produce some analytical way of estimating the flight loads accurately with the accompanying stress levels, frequences, etc , then the whole test does not mean anything What makes matters much worse is that the rotor which you ground test is subject to manufacturing tolerances and other non-uniformities which may by virtue of small stiffness changes have radically modified vibration frequencies from any other rotor The question to be answered is of what value is the ground test until you are in a position to correlate the analytically determined and the experimental flight loads If this can be achieved then we have a sound basis for the pre-flight ground testing Until we can do this any conclusions must be erroneous

Of course, once we have reliable flight figures there is nothing to prevent attempts by the usual techniques for simulating a given stress pattern But surely this reliance on flight results is hardly an ideal state of affairs for it means that we are admitting that we are not, at present, able to stress a rotor blade until it has flown, an admission which I find very disheartening, and which from the design aspect is very unsatisfactory

I should like to put one direct question to Mr Brennan I know that his company has been associated with the production of printed foil gauges Would he tell us briefly his experience with these gauges ? I am particularly interested in the question of uniformity of the gauges and the need for matching which has always been such a headache with the normal kinds

Mr Brennan (*in reply*) ° I feel very much like a lamb going to the slaughter but as Mr Hafner will be following me I feel more than sure that he will make up for my shortcomings I should like to deal first with the questions raised by Mr Fisher and Mr Williams and in particular tne comparison between the fatigue on the fixed wing and on the rotating wing aircraft

I feel there is a fundamental difference in these cases and inasmuch as the cyclic stresses predominate in the helicopter I think the case is more favourable to the helicopter When you have strain gauged an helicopter in the air and you have obtained all the stress levels and fluctuations you then know approximately how many reversals take place in any given period If these levels and fluctuations are acceptable you can be reasonably happy from the fat gue point of view In the case of the fixed wing aircraft, however, the fluctuations do not occur in anything that resembles a pattern, although some measure of the number of reversals per hour may be made But the accumulation of reversals is so comparatively slow on a fixed wing that it may not be until after 3,000 or more hours that you suddenly possess the critical number of reversals, and failure is imminent It is in this respect that I feel the helicopter is in a very much happier position than fixed wing aircraft At the present moment there is no requirement for strain gauging a fixed wing aircraft although certain measurements have been made in some development flight tests

With regard to the third order rotor frequency mentioned by Mr Fisher and which occurred in the transmission and articulation in flight, it is true that they were not present on the ground running tests, although they occurred during ground running at higher power and revs As Mr Fisher anticipated, the three times rotor fluctuation is reasonably small in transmission, although discussions on these levels are still in progress

I might say that the remarks I have just made prompt me again to draw attention to the similarity between the engine and the helicopter I am aware that the case of engine failure in the air is very much less serious than that of a rotor, but we must observe that in the case of the helicopter the very nature of the beast allows you to follow a procedure similar to engine practice in avoiding and covering fatigue failure by representative ground runs This procedure is not open to you in the case of the fixed wing aircraft That is the real point I would like to stress to-night

If I can treat the speakers remarks with reference to the subject matter Mr SHAPIRO, among other things mentioned flight test simulation and in particular he said that we were looking for something that we could not easily predict by calculation I entirely agree with him When we attempt to simulate an helicopter in flight on the ground it is not with the point of view of reproducing the stresses in the air exactly It is to find what part of the aircraft is going to fail and we do not anticipate failure in those parts that have been strain gauged In fact, we hope there is no doubt about these parts because if there were we would not let the aircraft fly in such a condition What we are attempting to do is to measure the mean and fluctuating stresses that occur throughout the flight envelope so that they may be used as calibrating stresses Into the aircraft on the ground we induce the stresses occuring in the air and if a sufficient number of points throughout the helicopter are available, then it seems logical that the flight case has been reproduced It is the achievement of this ideal condition that we are concerned with

Mr HODGESS asked about the undercarriage The Skeeter was, in fact, tested on its undercarriage and I agree with him that herein lies a hazard We in our short experience have learned to respect the animal when tethered and to note its different behaviour

On the question of slip rings, we experienced quite a lot of trouble from vibration The Electronics Department, however, were of the opinion that they could just handle the problem and we ourselves were not keen to embark on anything new We had consulted Rolls-Royce and they were using mercury rings but their diameter was very much less than we required I should say that we had considered mercury slip rings but as we thought we would obtain the answers with a conventional ring, we did not proceed

On the question of telemetering we had examined this matter in retrospect in view of the difficulty we experienced in carrying heavy equipment in the Skeeter However, the expense of the whole undertaking deterred us, although Rolls-Royce had been kind enough to indicate how they carry out similar work De Havillands were also consulted regarding their very large experience on Propellers There are, however, some fundamental differences in the problem and in particular the very much higher frequencies experienced both on turbines and propellers make the telemetering problem and, to some extent the strain gauge problem, somewhat easier than that in the helicopter

I will just deal with one or two points made by Mr WILLIAMS

I should say that at the present moment we are not faced with the problem of strain gauging rotor blades of a composite type Strain gauges are placed on the steel tube

The problem of wooden blades has not presented itself to us, in fact, we are going the other way, if anything, but I do agree with Mr Williams, when, I think, he did say that the real thing that matters is not so much simulation as the achievement or the reproduction of strain levels You can introduce what appears to be a simulated motion, but you may not have the necessary agreed distribution of loads

Turning to Dr Roberts' remarks and his mild criticism of the programme, I should say that this programme which we have followed, and which was agreed by the Ministry, has one or two disadvantages When the prototype is being built it is necessary to get it into the air in order to determine the stress levels and while these are being obtained there is just that lack of precise knowledge he mentioned, but every precaution is made to minimise this by ensuring that the prototype is strain gauged on the ground and then undergoes a 50 hour fatigue run followed by complete inspection and examination In practise it is the strain gauging and calibration that takes the time and we do not find that an aircraft is flying round for any long period at a time in an unknown state of fluctuating stress In fact complete records of a flight envelope of an helicopter can be obtained from just a few hours flying, so that it is a relatively short period before you have complete knowledge of the flight stresses

With regard to the foil gauges, we have had quite a bit of experience with these, and the main reason, we feel, that they are superior to the gauges we have been using is that you can pass a greater current through them There is, therefore, a possibility of getting a higher level of signal through your slip rings We are, however, at this time proceeding with the preamplifying of signals before passing them through the slip rings

Mr Hafner (*in reply*) Mr Fisher refers to the potential danger of helicopters due to the lack of redundancy in the rotor system and suggests for this reason the factorising of flight loads in ground tests I agree with this in principle, but would point out that if the load factor is too high, then the ground test has failed in its most important object, namely in the simulation of flight conditions

This latter point has been stressed by Mr Hodgess, who referred to the difficulties arising from the artificial conditions in ground tests, such as for instance, the tying of the aircraft to the ground, which obviously introduces entirely new dynamic characteristics It is for this reason that we in Bristol have decided to test the rotor on the rotor test tower and the remainder of the aircraft separately on the gantry

Mr Shapiro apparently has not much faith in ground testing and would prefer to test the aircraft by " flying under safe conditions " I do not know quite what he means by " flying under safe conditions " If it is to be assumed that *test flying* is the only practical means of establishing airworthiness, then such flying must include the exploration of the *whole* flight envelope which in my view cannot be a safe procedure with an as yet un-tried aircraft The very object of ground tests is, I think, the obtaining of this important information without incurring flying risks

I am sorry to hear that Mr Williams has been shaken by my statements to the extent of believing now that we are confronted with a practically insoluble problem Having been confronted with such problems for over 20 years, I have sympathy with his sentiments but I do not accept them as a good reason for loosing heart

Dr Hislop asked whether the paper by Mr Rosenbaum, giving a theory of cumulative damage, was acceptable This paper in my view has the merit of trying to explain the phenomenon of fatigue and is thus certainly a step further and better than the arbitrary " cumulative damage rules " However, we have still a long way to go in the exploration of this very difficult problem

Closing Remarks by the Chairman

Tonight we have listened to two very interesting papers, which provoked a very stimulating discussion and raised many aspects of the fatigue problem—as yet unanswered One might apply the Parliamentary phrase here also, to wit " The debate continues "

Mr Hafner did make an amusing reference to mythology when he started off his lecture, I wonder if Icarus before beginning his flight should not have consulted Sisyphus who had to go through the perpetual cycle of pushing a great boulder nearly to the top of a hill then lose control and have it roll to the bottom After a few years of this process quite a number of reversals must have been done and he must have been quite an expert on fatigue !

Now that we are at the end of our meeting I will ask you to join me in wishing our speakers well for their efforts in putting forward their views on this very important subject here tonight