more, that it gives one an idea of the vast field covered by a maintenance engineer

This lecture has been read by the courtesy of British European Airways, but any opinions expressed are entirely my own

Discussion

The **Chairman** said that Mr WILLANS had not disappointed us He had delivered an interesting paper, making it deliberately provocative knowing full well that not everyone would agree with everything he had said Such an approach had much to commend it, because, among other things, it opened up the way to a live and stimulating discussion

Mr Willans had referred to two types of equipment and it would be only fair to give some time during the discussion to the representatives of the Companies who were most closely associated with that equipment The major Service Users operated similar equipment, and their representatives should also be given an opportunity to comment He therefore proposed to invite representatives from the Westland and the Bristol Aeroplane Companies, and from the Royal Air Force and the Royal Navy to start the discussion Then the discussion would be thrown open

Mr F L Swain (*Member—Westland Aircraft Ltd*), said that Mr WILLANS had given an interesting lecture, but as Mr MCCLEMENTS had commented not everyone would agree with all he had said In that respect he himself had a few points to raise

First of all Mr Willans stated that the component lives of helicopters in his Schedule finished at 250 hours and at this figure he knew of no other vehicle which would travel as far as the helicopter could in this period with so little attention

The point here was that a stage had now been reached in helicopter construction, particularly with his own Company where component lives were gradually being raised to what might be called very realistic figures The tail rotor gear box in both helicopters produced by Westlands had an overhaul life of 600 hours When it was stripped after that period the gear box was in perfect condition and but for the fact that it had to be stripped it would run for a further 600 hours without further attention

His Company had main gearboxes with lives of 480—500 hours and here again on stripping, these gear boxes were found to be in excellent condition and replacement of parts was a rare occurrence It was a matter of crack detection and rebuild and the component went back into service

A large percentage of main rotor head components were overhauled at 500 hours and a small percentage at 250 hours

As he had already pointed out a stage had now been reached when component lives, particularly in the two helicopters built by his Company, had reached a realistic figure which permitted high utilisation In fact the S 51 serviceability was equal to any aeroplane of its size and weight at the present time

Mr Willans in his experience with British helicopters, had obviously met with considerable difficulty in tracking rotor blades and found it an impossible task at times He asked that tracking be abolished With the metal type rotor blade, as fitted to the Westland products, the simple method of a flag was used The blades could be tracked and remain satisfactory for as long as 400 flying hours The metal blade was not susceptible to weather, temperature, and humidity variations Furthermore tracking within $\frac{3}{4}$ in of each blade would give a smooth running helicopter

The servicing of helicopters, be the group large or small, could be made much simpler by the use of the unit change system Under that system the major components were replaced and the components removed and passed into the shops for overhaul With this method the time the aircraft spent on the ground was reduced by $33\frac{1}{3}$ per cent The total man hours required to operate a helicopter unit are considerably reduced because the unit change system permits a steady flow of work for Engineers who would normally have periods of inactivity when the helicopter was serviceable These economies are essential to all helicopter operators

Mr Willans said he agreed entirely with all that Mr SWAIN had said and, indeed, expected him to say it In the paper, however, he had been careful to put down only what had been found from experience, and therefore he had not dared to say anything like that himself, because there had not been enough experience as yet He only hoped Mr Swain was right

Mr G E Walker (*Founder Member—Bristol Aeroplane Co Ltd*), congratulated Mr WILLANS on highlighting so many points on helicopter maintenance that were of importance to the operator There were other considerations, however, such as low initial cost and low weight, which the designer had to take care of, and these requirements sometimes conflicted with those which were foremost in the minds of the maintenance engineer

He himself agreed that many failures of the working parts of helicopters were preceded by sight, sound or feeling, but some warnings could be so shortlived that there was no time to do anything about them

The policy " Let well alone ' was quite a good one, and one naturally wanted to make overhaul periods as long as possible Whereas the Bristol Sycamore started at 250 hours, one wanted to increase that to 500 hours as soon as possible But it should be remembered that the number of Bristol 171's in service was small compared with the number of American aircraft Therefore, the number of 250-hour overhauls was also small compared with the number of overhauls that had been done on American aircraft He thought, however, that there had been sufficient overhauls now at 250 hours to warrant a change

The taper roller bearing had been carefully chosen, and he believed that it was the most suitable bearing for the application In order to keep gears with wide tooth faces in true alignment it was necessary to eliminate radial clearance in the bearing, a condition which could not be obtained by parallel roller races and only in ball races by a similar adjustment by shims to that carried out in taper roller bearings The taper roller bearing was becoming almost universally used in car wheel hubs and back axle reduction gear mountings, both of which were cases where elimination of radial clearance was required He did not agree that it was necessary to have elaborate tools for the pre-loading of the bearings It could be done quite simply with an ordinary clock gauge

The design of the free wheel on the Bristol Sycamore was surely so simple that no American design could be simpler They might be on a par, but he would not suggest that the American design was any simpler It was not true to say that a broken spring could disconnect the main drive The ratchet teeth were pulled together axially by the thrust from the helical splines At least one American design with a roller type free wheel had also a spring which helped the rollers into engagement This probably applied to all roller types, so that there was a spring in each free wheel

Mr Willans had referred to the fatigue life of many parts of rotor hubs It was worth mentioning that Bristol hubs had no light alloy parts The load-carrying items were in steel with indefinite fatigue life In addition, the needle roller bearings on the main rotor did not require special techniques in mounting for correct assembly He believed this was a feature of several American designs

Mr Willans had raised the question of the low life on the needle roller bearings of the Bristol Sycamore tail rotor He himself agreed that the life was too low, but the parts were not expensive to replace He understood from Mr Willans that at least one of the American designs had a very short needle roller life on the main rotor hinge pins Perhaps Mr Willans would correct that if he was wrong

The tail rotor blades were not balanced and tracked except in manufacture, and to date he had not heard of any advantage in doing this But perhaps Mr Willans had something to say about it

He gathered from the remarks on clutches that the torque limiting clutches were thought to be fitted to the Bristol Sycamore to save weight in the transmission This was not so The main torque limiting clutch was fitted into the design after an accident in which, during ground running, a complete set of rotor blades was lost They were broken off at their roots, and it was found that this was caused by a sudden change of power from the engine The fluctuation of load was so great that neither transmission shafts nor blades could be made to withstand the load by any reasonable increase in weight In future designs, the company were incorporating the torque limiting feature in the main design of the clutch

In the main, clutches were designed on the centrifugal principle, because it offered a lighter design than the single plate with full spring loading Weight was saved by the use of centrifugal force

In connection with main rotor tracking, it should be borne in mind that the larger the rotor the more critical was the tracking It was therefore natural that the small rotor of American design should give the least trouble As the size of the rotor increased, the more important it became

Development work on improved means of tracking was going on, but complete elimination of tracking in service could not be achieved until blades were produced which did not change in form under changing weather conditions, be they metal or wood Mr SWAIN had said that metal blades gave good service without changing under varying load conditions

With regard to transmission shafts, the double Hardy-Spicer type of coupling was in actual fact a constant velocity joint There had been little trouble here, as Mr Willans had stated Presumably, he was referring to other types of constant velocity joint when he said they gave far too much trouble

There were many more points with which he could deal, but he would leave it at that

Mr Willans agreed that the double type of joint was a constant velocity joint, but he counted it—he said—as two separate ones It was the other type where the whole of the action took place in one unit that had given trouble

Mr WALKER rightly said that the metal blade was the only answer wooden ones would never be right

If the torque limiting clutch was put inside, they should, he thought, be able to overhaul it themselves That was something they must be able to do, and they could not do it at the moment Whether it was inside the main clutch or separate did not matter, if it had still to be there

As far as he could see so far, tapered roller bearings were very good But Mr Walker had not mentioned the major difficulty—the shim He had given no reason why peel-off shims could not be used This was what caused all the expense in overhauling gearboxes—the grinding of shims

Mr E Voss (*Member—Bristol Aeroplane Co , Ltd*), agreed that thanks were due to Mr Willans for raising so many maintenance points for discussion It was real pleasure, he said, to get at them in the open

In the main, he agreed that greater periods between overhauls were a ' must ' This was the only way to secure economic operation Also, success in achieved operation was measured by man/flying hour, and here he would like to complete Mr Willans' sums on overhauls of 2,000 hours utilisation per year

Mr Willans said it took, with 2,000 flying hours/annum, 3,800 man-hours to maintain the aircraft, and 20,200 man-hours for unit overhauls, *i e* , with a 250-hour overhaul life (or ' period ' as he would prefer to call it), there would be eight overhauls per annum That was 2,525 hours per overhaul for unit transmission This puzzled him, because overhauls had been done outside the parent company before, and by inexperienced personnel who had not seen an overhaul, or even a helicopter, and yet, under suitable supervision they had completed overhauls of the complete transmission, the airframe and an engine change inside 1,000 man-hours He did not know where the other hours had gone Perhaps Mr Willans could tell him

He had always shuddered at the thought of the peel-off shim The fixed type employed on Bristol boxes are a sound proposition

During the initial production build of the gear box, the operators determined the size of shim, and subsequently it was ground to the desired dimension On the overhauls carried out during operation, there is no need to alter the shim size providing there are not any major replacements In effect, on a gear box that has been stripped in good condition, the shim can be used as a first class inspection check against bearings that have not been properly seated Again the ground shim can be suitably marked with its production assy size and gear box " pairing " number

The need for grinding due to wear, would not be expected until the 1,500 or 2,000 hours mark at the earliest If one wanted to add to the shim, one could still not do it with the peel-off type the thing had to be scrapped

He felt Mr Willans should have pointed out in referring to the overhauling of the main rotor gearbox, which he admitted was probably the major component, that

drives were provided for vacuum, generator, hoist and windscreen wiper, and yet there were considerably fewer moving parts than in the American counterpart and that in itself lent to a much quicker turn-round On the whole, it should not take more than about 200 man-hours to overhaul the main gearbox, and that would be the longest man hour item throughout the complete transmission The main rotor hub had no bearing assembly techniques whatsoever It was of steel, and it was assembled by close tolerance work It should not take more than perhaps 100 hours at the very most The tail gearbox was reliable in the same way as the American design There should be no trouble and no scrap of major parts, and it should be done in not more than 50 hours Tail rotor blades should take 30 hours , clutches 40 hours , and shafting 20 hours About 500 hours should cover the overhaul of the complete transmission, and he was at a loss how to account for approximately 2,500 hours for B E A 's unit overhauls

Regarding pre-loading tools, they were not used at Bristol's and Mr WALKER had already dealt with free wheel springs

The torque limiting clutch was mentioned in connection with special equipment for overhauling aircraft It was unnecessary But he would agree with Mr Willans, that for economic overhauling by the operator, it should all be done under one roof Mr Willans presumably included in his remarks—engine starters, generators and the like On the starter there was also a clutch It had to be pulled off to check the torque and a rig was necessary for this He himself had found it convenient at two stations to exploit this rig so that it also pulled off the torque limiting clutch, so there should be no difficulty in this respect

Was it main blade tracking with which Mr Willans had trouble, or was he referring to the stability characteristics of the aircraft as a whole ? In detail, was the pilot complaining of lack of stick travel and not main blade tracking, or was it the vibration of the aircraft that could not be tracked out ? If it was stick travel, there was a modification by which the range of stick travel could be adjusted When the vibration trouble was eliminated from the aircraft by juggling trim tabs, and consequent loss of stick travel, it was not acceptable to B E A pilots Yet under the same conditions of stick travel, eight other operators involved were quite happy with the aircraft In fact, it would, he thought, be safe to say of all the aircraft in the field and flying that there had never been any complaint on tracking other than from the B E A

The point I wish to make is there is a misrepresentation of the term ' tracking ' as against the trimming out of the aircraft by the use of tabs

It was said that there had been no trouble with steel blades Here again he had had comparable experience when he was with the B E A The first 800 hours of flying with steel fabric-covered blades certainly gave a lot of trouble, and it made itself evident through control system of the aircraft as a whole

He would say that the B E A were flying 171 type aircraft at a much higher cruising speed than the S 51, for instance, and were seeking a much higher standard of flight, consequently, they were not so easy to satisfy nowadays

One point Mr Walker had missed on component overhaul periods was that the Ministry had now agreed to 400 hour overhaul throughout the complete transmission, and that was quite a good standard of achievement

He could not help raising a question about the tail rotor Mr Willans said that the tail rotor blades should be statically balanced during overhaul He would like to know why In production one statically balanced in a longitudinal and chordwise sense, and all the parts associated with the tail rotor were made to close tolerances There were no extra washers or packing pieces or anything one could leave off The attachment of the blade was permanently fixed, and the end fitting was a machined fitting He could see no logical reason why, once these blades were balanced in production—and they were balanced—Mr Willans should want to attempt to correct them in the sense of static balance

He was interested in the tracking of the blade, because there had never been any complaint other than that the bearing did not give more than 250 hours life 250 hours on tail rotor bearings, which were a cheap item, was very little to worry about, if one considered it the weakest link in the chain Again, this kind of thing could be done in the field, and the trouble should be quite easy to locate If it was the main rotor blade flap hinge bearings there would be something to cause alarm, but there had been a 650-hours accumulated on these, and the bearings were still going on merrily without replacement Mr Willans could no doubt confirm from his own experience that he had not replaced any flap or drag hinge bearings

His company always insisted on " cats' eyes " for tracking the main rotor blades,

but at the request of the Services they had developed a method of flag tracking or pseudo flag tracking which was successful All outside operators used flag tracking, where their own engineers used " cats' eyes " whether in sunshine or rain, by night or by day The results obtained were very good

The original request for equipment on the aircraft came from Mr Willans There was a demonstration at Boscombe Down, and Mr Willans was the only one who advocated cats' eyes The recommendation was adopted and both cats' eyes and flag tracking were put into all aircraft equipment It was interesting to hear that he had changed his views If he had any difficulty with cats' eyes for tracking, it would be a pleasure to discuss the subject with him

With regard to fuel tanks, he could not see why they should come out at 500 hours Working on a 2,000 hour utilisation, he would not think they should be on a calendar time basis

Mr Willans said the problem was a very difficult one He had expected these remarks, because if one separated out any one particular unit, it could be made to seem quite a small job in man-hours He entirely agreed that the gear box figures were not far wrong He could not accept the figures entirely because he had not had time to work them out But there was a lot of wastage in coming and going and taking things off, and that was where the man-hours went

Shims were the cause of much of the trouble He could not agree that they went back in the gearbox as they came out None of them ever had done it had always been necessary to change them He did not know whether the taper bearing had something to do with that One was, indeed, working down a wedge and quite minute wear that one would not have regarded as serious had caused end movement of quite another order One had therefore to put in a new shim, and it was not like a peel-off shim One had to mess about, trying to find the right thickness and get it ground Then, possibly, it was not right and one had to do it again That was where time went

Peel-off shims were possibly scrapped because they could not be made thicker That was quite true But he did not mind scrapping a shim , that was nothing It was the time that mattered If too much had been peeled off a shim it could be thrown away and another one used From the time-saving point of view, it was a quicker job and he had never found anything wrong with it He thought Mr Voss knew this, for he had overhauled American gearboxes

Mr Voss said he had, on the fixed shim He asked whether in all the overhauls he had done Mr WILLANS had ever had anything wrong with his gears

Mr Willans No

Mr Voss asked whether he had ever had anything wrong with his bearings

Mr Willans said there had been one bearing only where some external material dropped in

Mr Voss said it was surely wrong in principle after 250 hours flying to scrap the shim because the end nip check indicated the wrong dimension Surely it was more likely to be incorrect assembly and not shim size

The Chairman suggested that as time was getting on they had better leave shims and get on to the next subject

Mr Willans, continuing, said that Mr Voss had misquoted him a bit on tracking He had said they had not had any trouble on the basic fabric and steel type of blade That was quite true But they did have trouble in tracking, he agreed He had not changed his mind about cats' eyes He thought one could get a better track with them But there were disadvantages because one was often away from a source of light He had also found, unfortunately, that engineers today preferred the flag He had tried to argue with them, but they did He himself did not think it was as good

Unfortunately, the 400-hour overhaul did not apply to B E A They were a long way behind that and never seemed to catch up They were not allowed to use these military lives at all

On tail balancing, in spite of what Mr Voss said, where the separate blades were dealt with and matched, a tool, a mandrel for balancing had been produced, and they were out He could not tell why but they were out

The 250-hour life had never been achieved at all on the flap hinge bearings, nothing like it They were gone in no time, and one was lucky to get 100 hours

Mr Voss said it was unusual

Mr Willans said that was not the case with the B E A That was why he felt balancing had something to do with it It was possibly nothing like the whole answer, but it would help Every little thing helped There had also been complaints of tail vibration in the aircraft and that had been cured by changing the bearings or the rotor It was one or the other Therefore, again, the balanced rotor would help As regards fuel tanks, that was not a Bristol aircraft, but the particular aircraft they had called for them to come off at that time Whether they could argue their way out of that later he did not know

Sqn Ldr G C Matthews (*Aircraft Engineering Branch, The Air Ministry*), said he must make clear that he was a serving Royal Air Force officer and any comments he might make were not the official Air Ministry or Royal Air Force point of view but his own views gained from experience in the Royal Air Force

The problems connected with helicopter maintenance had been very well expressed by the lecturer and his information lined up in a general way with what one found in the Service However, the way in which helicopters were deployed and the method of recruiting maintenance personnel were such that the R A F were compelled to solve their problems differently from B E A

Mr Willans said that maintenance was a profession calling for individuality and that the subject could not be taught Unfortunately, in the Air Force men had to be taught to service helicopters who had no experience and very little aptitude for the work This was particularly true of the semi-skilled man who was generally the National Service recruit The more skilled technician or N C O, who had had a good basic training in aircraft engineering or who had been a Royal Air Force apprentice, found an interest in the helicopter because of its own special problems and his keenness to find out all about these unusual aircraft instilled an interest in the semi-skilled man

Although it might be desirable, the R A F did not have specialised helicopter tradesmen, and there were no routine arrangements to make sure aircraft fitters were continuously employed on this or any other particular type of work In spite of this, the helicopter force had recently been successfully expanded, and new types were operating under rigorous conditions in various overseas theatres at high intensity

This was particularly true of numbers of helicopters in Malava, where day-to-day servicing was done in the open and where helicopters were kept for most of the time uncovered in climatic conditions which varied from torrential rain to hot sunshine

Before a new unit was formed, the more skilled tradesmen or supervisors were given courses of instruction at manufacturers works On the formation of a new unit, a manufacturer's servicing representative was often called upon to advise for a few months But after the initial period, the R A F technician generally settled down quite happily to the job

The R A F tried to follow the "Leave well alone" policy, but because men were constantly changed, passing from one unit to another, they could not rely upon retaining men with enough experience and judgment to enable them to know when to leave alone In consequence, a servicing schedule was worked out which told each tradesman exactly what to do and when it must be done

The technician or N C O was called in to diagnose running faults and he relied to a large extent on the reports of the pilots It was agreed that working parts generally gave warning of impending failure and that fatigue was the dreaded bogy that came without warning It was because of this that routine breaking down of components was the most important and expensive part of helicopter maintenance However, more and more was being found out from practical experience about this

During the past three years there had only been one case of fatigue cracking which caused a major failure Following this, cracks were found in the same part in other aircraft, and since then modifications had been introduced and there had been no further trouble Apart from this isolated accident, nothing had happened to confirm that the practice of routine crack detection of components was really necessary By that, he meant from the practical results point of view

Although he did not think the stage had been reached where it could be said that parts did not need to be dismantled for examination at set periods, the time had come to re-examine the problem, and he agreed that the periods need not be so short As the Bristol representative had suggested, they ought to think in wider terms in the light of their experience

Accessibility and ease of removal was, he thought, quite good in present-day helicopters, but they ought to work for something far better than they were getting at present—say, complete removal and replacement of components in twenty-four hours That would have to be achieved, of course, through better design

Another point for the consideration of designers might be the introduction of a clutch between the main rotor and the gear box, so that in the event of a complete failure of any part except the main rotor and controls a safe auto-rotative landing could be made This would permit routine fatigue checks to be concentrated on these parts only The remainder of the transmission could then be given a much longer life between overhauls

The R A F system of servicing was very similar to that described in the lecture The schedule called for routine checks in respect of flying hours and calendar periods and was first used in all Commands, whether operating in tropical or temperate climates It was amended to suit the needs of local conditions, as experience dictated Up-to-date there had been partial experience only in the overhaul of main components but it was hoped shortly to take over the job completely

It was agreed that test rigs should be provided, as suggested by Mr Willans, and that tools required to dismantle and re-assemble parts were too many and too expensive

The ideal that overhaul workshops should be close to where the aircraft was serviced could not be achieved Maintenance bases had to be selected at strategic places for overhauls and components had to be carried to and from the aircraft This put up the cost of transportation and the holding of stocks These were some of the things that must be accepted

Mr Willans said that very little comment was needed from him He was extremely interested to hear about the different method of operation He thought he agreed about crack detection, but he would not dare to omit doing it The subject was an extremely difficult one One almost never found a crack, with all this elaborate equipment, that one could not see with one's eyes But occasionally one did find one and for that reason one dare not drop the test

Lt-Cdr M Hayward (*R N A S, Gosport*), said he would like to point out that he also was not officially representing the Royal Navy Any statement or opinion expressed by him was entirely his own and not that of the Admiralty

He would begin by flogging the nearly dead horse of tracking The Royal Navy had a slightly different problem, because they had constantly to fold and spread the main rotor blades for striking the aircraft down on board They had found that tracking was not only necessary but absolutely essential In fact, he found on board at one time that to produce a really good vibration free aircraft, it was desirable to track every day before the aircraft flew

This could be done in about ten minutes, using the flag method If one had tracked primarily, stopped the rotors and made the adjustments on the short push/pull rods one could allow the aircraft to go off on its first sortie If one had time on landing, and the engine could be kept running, it was desirable to give a check tracking to see that the initial adjustments were correct

Again, from the naval point of view the matter of the main rotor brake was very important It might be necessary to start up with the wind force over the deck of up to 60 knots This condition could often be reached in a wind of 30 knots with the carrier steaming into it at 30 knots Under these circumstances one made a " quick start " which required a very reliable main rotor brake To do the " quick start " all the engine checks, except the full power check, were done before the rotor was engaged When the pilot was satisfied with his engine, he would release the brake, engage and take off immediately

In the same way, when operating aircraft in a hurry, if one had to fold the blades for striking down one obviously had to stop them as rapidly as possible

It had been found that the rotor brakes of the two types most frequently operated from carriers were quite satisfactory In the Whirlwind the brake was, in fact, first class

Servo controls had been referred to by Mr Willans These controls were fitted to the Dragonfly and Whirlwind aircraft and his own experience of servo controls was that they were absolutely trouble-free once they had been initially set up

An interesting point raised by Mr Willans was the removal of the undercarriage This was not considered practical for naval aircraft as they still had to be moved about when on the deck

With regard to Mr Willans' remarks on test flying he did not find that a 1,000 feet cloud base was required He had personally found that with caution the auto-rotative r p m check could be made quite satisfactorily from 200 to 300 feet

Atmospheric conditions had been found to effect Hiller blades and their balancing These blades are of composite wood and metal construction They were, however, very easy to track by the flag method and it was also easy to eliminate any " out-of-track ' by use of trailing edge trimming tabs

The comments of the last speaker on personnel for servicing applied equally to the Navy The problems were the same and they were overcome in much the same way

Personally, he had found all the helicopters with which he had had to deal were excellent aircraft for maintenance They flew much longer hours not so much between replacements as between failures

Perhaps he might be allowed to close with a short story, which brought out the rugged nature of the helicopter During the Greek earthquake disaster of 1953, a pilot was required to lower a signal bag to the quarter-deck of a cruiser, which he did by means of the winch A sailor removed the signal bag from the winch hook and being trained like all seamen to be extremely tidy did not like to see this swinging round, so carefully hooked it over the guard rail The pilot was quite unaware of this, because one cannot see the winch hook from the pilot's position, so he started to " winch in " He remained unaware of the fact that he was attached to a very large and heavy cruiser, but did become aware that the aircraft was sinking rather rapidly, and he therefore applied full power and some collective pitch, and the aircraft rose with a jerk, the winch wire having parted The wire whipped up and removed from one blade about 6 to 8 feet from the tip end The aircraft continued to fly, for about 28 miles, and landed safely

Mr Willans expressed interest in these comments There were still one or two points, he said, about tracking He did not see how one could track in that way, just make an adjustment and fly off The B E A would not get away with that They carried passengers, and the machine must be smooth-running They got endless complaints unless it was At 200 feet one was inside the forbidden envelope People would not do it They had to complete the whole of their auto-rotative cycle under control while above that, so they were forced to have good weather to do it

To return to a point raised by Mr Voss, they got a large amount of tracking trouble It was true that they had had two cases of bad out-of-trim, and in the end that was found to be due to moisture in the blades The main trouble was plain tracking It was not a trim of the aircraft involved

Mr J Leason (*S L A E*), thanked the Association for their invitation to attend the lecture and take part in the discussion He congratulated the speaker on an excellent paper, bearing in mind that a lot had already been said about maintenance Everyone must appreciate the long and tedious hours he had put in to produce a paper of its calibre

He himself had always felt that the rule of " Leave well alone " was far more suited to the lazy motorist than to the helicopter maintenance engineer If it was to be used in that sphere, one had to tread very warily indeed He did not think the stage had yet been reached in helicopter development where this rule could be adopted *ad lib* " Prevention is better than cure " would be a better rule Perhaps it would be a little more expensive at the time, but in the long run it would be much safer, and safety must take precedence in these matters

With sealed components, such as the gearbox or rotor head, one could not help but leave well alone until the end of its approved life But care must be taken to see that the outlook of the engineer or inspector was not imbued with any kind of complacent doctrinaire which might be prevalent in his working environment and which might induce him to skip his inspection a little because he felt he should leave well alone This was not a supposition but a fact He must be vigilant and be prepared to look for and find defects that would indicate that all was not well within the sealed component before the end of its life

He would remind the speaker that there had been a control failure on a rotor head of a 171 that was not a fatigue failure and one that gave no previous warning by sight, sound, or feel on this particular occasion

As to the less important components, such as helicopter legs, and so on, it was wrong to wait until they failed or showed signs of failure In the case of the S 55, he would go so far as to say that it would be decidedly dangerous Give a long life as possible by all means, but let there be an overhaul at a set period when seals, bearing surfaces, fluid condition and cleanliness were reaching deterioration point That point must be established

The same policy must be maintained for minor components Otherwise, failure was sure to occur at the most inopportune moment on service This would unfortunately involve greater expense and inconvenience with additional loss of prestige for the operator and his equipment in the eyes of the travelling public Suppose, for instance, there was an undercarriage failure with passengers on board away from base This must be avoided at all costs, for in the end it would only reflect inefficiency

No-one wanted to tear components to pieces unnecessarily for the sake of seeing that they were still all right But a compromise might well have to be made on this point, when dealing with new types of helicopter under development

He felt, therefore, that the aim and responsibility of the B E A Helicopter Unit was to gradually find the ultimate life of all components as soon as possible, and by careful annotation of defects and replacements at overhaul periods it could soon assess the greatest extensions that could be made with safety and reliability

Maintenance schedules should be compiled or at least checked by someone licensed on the type of helicopter and then approved by the A R B also by someone conversant with the maintenance side

With regard to fatigue cracks in various ferrous and non-ferrous materials, the well known proprietary methods were used These showed cracks if already there In an experimental unit other methods could be tried out, whereby it could be ascertained whether it was possible to anticipate cracks by, say, the use of ultrasonic or X-ray equipment Neither, as far as he knew, had been used in this country for helicopters If these methods could be tried and evaluated it is probable that some substantial increases in lives might be obtained with a greater measure of safety in a fleet of helicopters on passenger-carrying service The cost of such equipment would not be so prohibitive as might be imagined Only recently Capital Air Lines of the United States had introduced a new portable X-ray apparatus for use on Viscount aircraft

In a comparison of gearboxes, the speaker said there was almost total absence of bevel gears and compared them with parallel gears The comparison should have been between epicyclic and straight and parallel gears After all, they were the two main methods of reduction All the main gearboxes with which one was familiar had a number of bevel gears in them, mainly for ancillary purposes and take-off drives All intermediate and tail rotor gear boxes were of the bevel type and had given excellent service in the past

He agreed wholeheartedly that complicated procedures for the assembly of gearboxes and excessive and costly tools with which to carry them out should be avoided

He was afraid tracking would never be satisfactory until a wonder blade was produced It could then be reduced to a minimum

He disagreed as regards night tracking not being satisfactory He had always found well coloured " cats' eyes " with a powerful lamp gave a clear indication With two blades it was easy to observe, with three it was a little more difficult But he would not like to say that he could differentiate between four colours if and when these four-bladed rotors came along With regard to root bearings he was not sure whether the speaker meant sleeve, flapping, of drag-bearings, or all three

He was pleased to hear that the representative of Westland's thought it possible

to go 400 hours without tracking, but he had found that there was a variation of tracking or requirements for tracking not so much with variation of blade but probably with variation of flying staff

On time taken on overhauls those on the inside of Bristol's might be lucky, but those outside had probably to wait for spares, and four or five months waiting was commonplace

As regards the last speaker, he would like to know how he did a magneto check without engaging the rotor

Lt -Cdr Haywood Put the switches on

Mr W J Gibson (*British Timken Ltd*), said he wished to confine his remarks to the subject of bearings, and in particular to the tapered roller bearing which he felt had been unfairly dealt with by Mr J H WILLANS

Without the full knowledge of the estimated life hours between British and American gearboxes, no direct comparison between the bearing types could be assessed, but from his own limited knowledge of American designs, he would say that the bearing life expectancies were at a higher value on the British machine than on the American counterpart

Timken tapered roller bearings were, as the author had stated, used almost exclusively by British designers and, he would submit, to some extent by American designers He believed these bearings were incorporated in part at least in gearboxes designed by Hiller and Piasecki and in other applications by Sikorsky It might well be that in the case of Sikorsky some influence had been achieved by the incorporation of these bearings in the anglicised S 51 and S 55

Dealing firstly with the question of bearing weight, this had been answered in part by his previous remarks, but he would like to point out that the tapered roller bearing had generally speaking a higher load-carrying capacity in lbs per lb weight of bearing than any other type of rolling bearing In fact, weight saving could be achieved by the employment of tapered roller bearings as against other types, *e g*, a duplex type ball bearing which was used on the Air Horse and weighed approximately 13 lbs was replaced by a two-row Timken tapered roller bearing weighing only 8½ lbs

The inherent advantage of the tapered roller bearing was the versatility of the design which enabled any ratio of radial to thrust capacity to be incorporated within the limitations of specified boundary dimensions

A further advantage of the tapered roller bearing was the ability to effect the exact amount of adjustment desirable, and this condition also ensured maximum stability, since it was also possible to pre-load the surrounding structure as well as the bearings to limit the amount of structural deflection under normal working conditions

One had, for example, got to accept the internal clearances of ball and parallel roller races which also imposed strict limitations on the fitting tolerances between the mating shafts and housings, since interference fits would impair the efficiency of these bearings This problem did not affect the tapered roller bearing but it did mean that the extraction of these races was obviously not so simple as the above types

From the point of view of initial cost, here again he would say that if one considered cost in terms of bearing capacity and also bore in mind that one was dealing in a competitive market, the differences in price, if any, were negligible It would be true to say, however, that if one was thinking in terms of the cost of special bearings which had been designed for a specific requirement and the quantity of bearings involved was small, then these bearings, whatever their type, either ball, roller or tapered roller, would be considered expensive in comparison with the prices charged for standard products This was particularly true in cases of bearings having slender sections which required special manufacturing techniques

Mr J S Shapiro (*Founder Member—Consultant*), said the lecture was absorbing, and any designer could produce a counter-lecture of similar length by way of discussion The paper touched on so many subjects, and everyone had views on almost every one of them He would, however, refer only to two points on which his experience might be valuable

First, he thought there was some confusion about the principle of " Let well alone " He knew of one instance where almost certainly looking inside had proved

much less safe, so it was not necessarily a question of looking inside and making it safer He would like to warn all maintenance engineers very seriously that looking inside could actually produce a failure The mere attempt to try whether something was well fastened might produce much bigger loads than any that could be put on in flying That must be remembered "Leave well alone" was a very important principle They should think about their machine and almost dream about it They should not look inside unless they knew what they were doing

Secondly, the speaker had described fatigue as the designer's problem, one with which the maintenance engineer had nothing to do He thoroughly agreed that it was the designer's problem In fact, he had stuck his neck out severely in saying so almost without reservation Nevertheless, the maintenance engineer had something to do with it Fatigue failures could be eliminated by proper design—only on condition that maintenance and inspection carried out what the designer had in mind It was a question of finish, alignment and very often wear

It was a very important principle in design, that in many moving structures a redistribution of load was produced by wear Sometimes this redistribution was good and sometimes it was bad In the Bristol 171 flapping hinge it was good One could get a better spread But in some designs there was a bad redistribution—in fact, perhaps a fatal redistribution Therefore, while it was best not to have designs of that kind, nevertheless it might be good enough to have a design with a possible bad redistribution where trouble was avoided by proper maintenance Redistribution through wear could also cause completely new and different fatigue conditions halfway through the life of the assembly, and therefore, change the whole situation

Mr T G Newberry (*Member—Ministry of Supply*), said that Mr SHAPIRO had touched on the main point he wished to mention—the "dreaded bogy" of fatigue He did not agree that this was "entirely the responsibility of the designer" The designer had a big responsibility, of course, in fatigue-proofing his design To take one point, he should do everything possible to reduce stress concentrations The next step was to do rig-tests, as suggested in the paper, to prove the fatigue strength of the item

Even when an item was tested and its fatigue strength was established, however, that only applied to the item in the condition in which it was tested The fatigue life which could be established as a result of the test only held good as long as the item remained in that condition Unfortunately during the use and operation of most of the parts of a helicopter the condition deteriorated

Another point which should be emphasised was the problem of corrosion, in particular fretting corrosion, which could produce very severe stress concentrations That, he thought, was one of the main justifications for stripping and inspecting the components of the helicopter He did not think that fatigue freedom during the overhaul life should be based solely on crack detection, because the fact that no cracks were found in a crack detection test was no guarantee that there would not be a crack and a failure during the next overhaul period It depended upon the amount of fatigue which the metal had suffered and the production of such conditions as stress concentrations which could cause failure during the next overhaul period Obviously, crack detection was a natural part of inspection, but it was quite wrong to rely entirely on crack detection tests to ensure freedom from fatigue

The main justification, in his opinion, for overhauling and inspection at relatively frequent intervals, was to ensure that all parts were in good condition and would be safe for the next overhaul period This influenced the length of the overhaul period and in some cases the overhaul periods fixed at present were low One of the reasons for this was that until experience was obtained on how parts stood up to service conditions it was not possible to say how long they could be left alone before fretting and other deterioration made them dangerous

As far as the Service was concerned, the overhaul period was fixed to start off with at what was thought to be quite safe As experience was built up, the period was extended, and that was the only safe method, he thought

It was said in the paper that ferrous components had a fatigue point of 10 million reversals beyond which they would not fail That was generally true of laboratory test specimens, but it was not necessarily true of built up components or of components manufactured by normal production methods Particularly, it was not true of parts subjected to wear and tear or fretting

He was very interested in the suggestion about a device for anticipating the formation of a fatigue crack If only someone could produce such an instrument,

it would be of tremendous value Unfortunately, as far as he had been able to ascertain, nobody had as yet been able to find any means, or any method of inspection of the metal itself, of showing how far it had progressed in its fatigue life—how near it was to the formation of the initial fatigue crack This was something many people had in mind, and one day perhaps some solution would be found, but until then one had to work on the safe side

The torque limiting clutch in the new Bristol design was not a separate item The torque limiting feature was built in as part of the design of the clutch, so that one clutch fulfilled both functions

Finally, might he add a similar note to that of the Service personnel What he had said was purely his own opinion and must not be taken as representing in any way the opinions or views of the Ministry of Supply

Mr I Chichester-Miles (*Hunting Percival Aircraft Ltd*), said he would like to ask a question to clear the minds of those—like himself, who did not know a great deal about the practical operation of helicopters He was working in a firm that was trying to cut down the cost of maintainance by two methods The first was by using a system of jet drive, and the second by using only large mechanical components that shall have a long life

Could the speaker give any idea, if one paid 1/- per mile to travel in a helicopter how much of that 1/- went to maintenance and replacement

Mr Willans was sorry he could not answer that question they only dealt in engineering with the currency of man-hours He did not know the £ s d

The **Chairman** said that Mr R H WHITBY might be able to reply to it

Mr R H Whitby (*Member—B E A*), thought it would be about a penny or twopence

A vote of thanks to Mr WILLANS, proposed by the **Chairman,** was carried with acclamation

---

Written contribution by F L Hodgess (*Member—Fairey Aviation Co Ltd*) Mr WILLANS is to be congratulated on a very thorough presentation of the maintenance problems experienced with the conventional type of shaft driven helicopter I would like to select some of the points that Mr Willans has raised in the light of the experience we have gained in the running and maintenance of a a tip driven helicopter

(1) I agree entirely with Mr Willans that continual running of unit components to a point where the fatigue life is definitely established should be carried out before going into production As gear boxes and transmissions with their associated bearing troubles seem to have caused Mr Willans much anxiety it will be perhaps of some hope for the future that these components have been mainly eliminated with the adoption of the jet drive

(2) Regarding the tracking of blades which has always been a necessary evil in the past, this problem appears to have solved itself in the case of large all-metal tip driven rotor blades The suppression of the drag hinge, the torsional rigidity inherent in any blade which has to provide a large air duct together with the mass of the jet unit at the tip of the blade, would appear to be the major reasons why we have never had to track the blades of the jet Gyrodyne either on the ground or in flight

(3) I do not agree with Mr Willans that running the rotor of a helicopter while tethered is a good way of testing rotor head components for wear or fatigue In my experience the forces and loads imposed upon the rotor head of a tethered helicopter are so unnatural as to cause, in many cases, stresses and therefore possible wear on parts which in the air would never be subjected to similar loads

(4) I am in sympathy with Mr Willans when he asks for stronger rotor brakes For the sake of an extra pound or two in weight a real contribution to the safety of the aircraft itself as well as to the adjacent populace could be obtained

(5) Regarding power controls, our experience has been that provided a well proven system is employed, these components give no trouble and even where the systems are duplicated the additional safety is well worth the extra complication