DISCUSSION.

Mr. R. Hafner (Messrs. Bristol Aeroplane Co. Ltd.) (*Member*): This subject of maintenance is of very great importance, because it brings us directly to the very core of the problems connected with the present development. Our scope is much wider than that of just maintaining the helicopter; the designer, the operator, the maintenance engineer, the licensing authorities, and many more people are involved.

The pioneer phase of the rotating wing has been completed successfully, and we find ourselves today in the less romantic transition phase. We have demonstrated that the helicopter can fly and carry a useful load, and that it can be manoeuvred satisfactorily. On the other hand, its commercial exploitation, or its full utilisation, has hardly commenced. In the present transition stage it is our responsibility to show, not only that the rotating wing aircraft can take the air, but also that we can keep it in the air consistently, cheaply and, above all, safely.

The present designs are in the process, I think, of proving these points, with increasing success. This process is carried out substantially by a series of modifications resulting from criticism. During this transition phase, therefore, we must welcome modifications and not look upon them as evils; they are the true expression of life in this vital evolution. After each modification new criticism will surely transpire, until eventually we arrive at the mature article; and at that moment the transition phase will have come to an end. Therefore, I regard today's criticisms as evidence of a temporary condition in a rapidly changing scene; and from the very valuable collection of papers which have been put before us I am trying to give you an answer from the designer's point of view.

In the paper by Mr. Voss a case was made out for progressive servicing. He would like to see an aircraft which is designed such that he can break it easily into parts and can deal with each part separately at very frequent intervals, preferably every evening; that is probably the logical point of view of the man who is operating his aircraft daily to schedules. It can very well be done. One would thus obviously design the aircraft as an assembly of a large number of small and convenient units, but with a warning to the operator that a certain penalty would have to be paid in executing such a policy. However, that may be the optimum solution to the problems of that type of operator.

On the other hand, there are some who prefer the block system of maintenance. That is a logical one for those who may be concerned with seasonal work or with the irregular operation of helicopters, such as for traffic control, military, ambulance and police work, and other. Such operators would require to use helicopters over a given period, during which they would work at great intensity, and during that period of operation they would want maintenance work to be reduced to the minimum; after that period there would probably be an interval during which their aircraft would be overhauled and made ready for a new period of operation. Such a case, too, can be met by the designer, but the ideal design for this case will obviously differ from that for the scheduled operation. Instead of emphasising the means for breaking up the aircraft into small components, the designer would think rather of ensuring that the unit as a whole would have a given life, sufficient to enable the operator to use the aircraft throughout the critical periods without interruptions ; the life might be 1,000 hours, or something of that sort. That may result in generally heavier parts, but on the other hand savings may be effected by reason of the fact that the design is not broken up into small components.

Then there is the question of ground equipment versus equipment carried in the aircraft. As Mr. SHAPIRO has pointed out, this is mainly a matter for compromise. The military man or others whose aircraft may have to operate in jungle country, away from suitable bases, would wish to carry on the aircraft as much equipment as possible. A very good idea but, of course, the operator would have to pay the weight penalty. The airline operator, on the other hand, obviously would take the diametrically opposite point of view. He would have well-equipped service stations at the termini of his regular runs, and would prefer to load his helicopters with fare-paying passengers rather than with maintenance equipment. These two opposing sets of requirements cannot be met in the same design.

The view was expressed by Mr. BRISTOW that the helicopter must be simple and that there must be no modifications. I fully endorse this view as a general principle, but I must warn against the dangers of generalisation. If this principle was generally valid, then amongst fixed wing aircraft one of the best designs would perhaps be the Auster, and one of the worst the Constellation. This clearly is not true, as both aircraft are examples of good aircraft engineering, considering the use for which they have been built. It is unreasonable to ask for *the helicopter which can do everything*, but we must realise that we need various types and some of the criticism raised today can, therefore, be met by one type of helicopter, and some by another.

It has been mentioned that rotor blades are rather delicate and that tracking is difficult. Rotor blades are indeed delicate, because they revolve at very high tip speeds, and are subject to considerable aerodynamic effects, and therefore we need very close manufacturing tolerances. With all-metal blades we shall probably achieve such tolerances, but with the wooden structures of today they cannot be achieved consistently, or, with the weather and other factors acting on the blade, are often lost after a short life.

I have found from experience that very often rotors deteriorate, not due to weather or other factors over which we have no control, but due to ill treatment. Rotor blades are slender structures and are naturally sensitive to handling; especially the trailing edge must be treated with care. This is a very serious point.

As regards tracking, I feel that in the near future we shall have suitable equipment which will make this a routine procedure.

Another matter mentioned was that of ground rigs for the testing of moving parts of the helicopter. This principle has been adopted by the B.A.C. ; we are testing rotor blades, rotor hubs, gear boxes, and other transmission parts, on ground rigs, and we have proceeded a good way along these lines ; but I do not think the small operator, having only two or three helicopters, could afford expensive testing equipment, and in his case I think it would be best for such parts to be returned to the factory, where the necessary inspection, as well as rig testing, can be carried out. I think we have recognised that rig testing plays a vital part in helicopter maintenance.

Then Mr. ROWE mentioned the very important point of testing components of new types on ground rigs. We fully agree with him on that point. We think that the quickest way to gain experience on a new type is to extract the mechanical components from the aircraft after completion of the C. of A. investigation and to continue to run them on ground rigs capable of simulating flight conditions.

I listened with very great interest to the paper by Mr. COOPER, dealing with materials. I know that he is a great authority on the subject and I do not wish to contradict him in any way, but I would like to ask him one question. He has mentioned the endurance of various materials, particularly that of wood and steel. He has shown that the fatigue strength of compressed wood—such as Jablo wood—is 4½ tons/sq. in. at 50 million reversals, whereas the corresponding figure for steel is something like 32 tons/sq. in. He concludes the wood is inferior to steel. However, it seems to me we are not concerned so much with the absolute figures but rather with them in relation to the weights of the respective materials.

I would like to ask Mr. COOPER if he thinks it is the fatigue strength which is making wood less suitable than steel for this sort of work, or whether the reason is connected with notch sensitivity. I cannot help feeling that even now we still have a good many wooden propellers doing useful work, which are, I think, subject to exactly the above considerations.

Mr. O. Fitzwilliams (Messrs. Westland Aircraft Ltd.—*Founder Member*) : I should like to say first that I hope that this meeting today, at which constructors and operators have willingly met together to discuss their faults, will serve to disperse an illusion which I think sometimes affects operators ; that is the illusion that the designer is in some way on the other side of the fence, and that he generally views the operators' criticisms as unreasonable. I do not think that any thinking man really believes that, and it should be recognised that the manufacturer is, in a sense, an operator himself. He demonstrates all over the place, and he is also an operator with a particularly difficult problem, in that he is operating a prototype, without the aid of extensive Manuals or ground equipment.

I propose to try to remove some of the gloom which seems to descend upon people listening to these complaints. I will try to make simple statements indicating what is wrong with the present helicopters, what I think the solutions are—I believe they are very obvious and simple—and what effect I think these solutions will have. I hope you will agree with me that this is a matter of time and money and so forth, and that there is nothing fundamental about it at all.

The complaints boil down to insufficient provision for maintenance work, inadequate provision for maximum overhaul periods, and component lives, and not enough attention to the detail design of the aircraft and its ancillary equipment.

The improvement of the ancillary equipment has worried the manufacturer far more than the operator. Type Test endurance running, the test running of production helicopters and the sometimes extensive running required in matching sets of new blades, have all been made difficult by the fact that present helicopters were not designed to be tied down easily, so that rather clumsy adoptions have been necessary. I think that simple provision for tie-down tests will be part of future helicopter designs, since a daily full power check by the operator does not seem to me an unreasonable requirement.

Improved provision for tie-down testing, together with reasonable all-round improvement in other ancillary tools and equipment will, I think, save some 10% of maintenance work on future helicopters.

Detail design improvements were not really possible a few years ago, for there was not the necessary background of experience in the design offices. Nowadays the chance of improvement is much better. Considerable improvements can result from even such small matters as the jig drilling of split-pin holes ; one can spend two or three times as long on the installation of a split-pin as should be necessary.

Both the ancillary equipment and detail design will be sorted out gradually on existing types, but we can start with a much better chance on new helicopters. I think that the cleaning up of various parts, the provision of sensible connections for controls, and so on, will enable us to effect probably a 15% further reduction in the energy to be exerted by service engineers.

Undoubtedly the biggest single design contribution will be made in the primary layout of the helicopter. I believe that perhaps 50 or even 60% of the time spent by service engineers on helicopters which are now in operation is devoted to taking off major units and putting them on again. I do not think this is much affected by whether you are working on the progressive or block maintenance system, for the parts have to come off and must be put back again, whether you put the same parts back after waiting for them to be repaired, or replace them immediately.

I think the biggest advance that will be made amounts simply to abandoning the practice of burying the engine and other major units inside the main structure. The engine mounting of the Air Horse seems to me a good example of the trend toward external mounting of major units, and inspection of the new S-55 helicopter will also show that all the major components are outside the main airframe and are easily removed, and the attachment of the components to the airframe has been very much simplified. Perhaps the reason for Mr. Bristow's enthusiasm for the Hiller is that a similar effect has in that case been achieved by omitting the outside altogether ! I admire the Hiller, and I am only concerned here to point out that the same advantages can just as easily be made available in other helicopters.

I believe that improved primary lay-out will result in a saving of up to two-thirds of the time now spent in taking things off and putting them on again ; and if that is now 60% of the total, there should result a saving of 40 to 50% of the total time now spent in servicing. I have not added up all these percentages, and if we go much further I imagine we may arrive at a negative servicing time ! But I believe that by improved primary lay-out and closer attention to detail design of the aircraft and its ancillary equipment, we could probably reduce servicing work to one-third, or maybe less, of its present value.

Of even more importance than design improvements is the over-riding question of overhaul periods and the fatigue life of components. The increase in overhaul and fatigue life goes much further than design improvements in reducing the total work, because even the reduced work on the helicopter can be halved or quartered by doubling or quadrupling unit lives. A very great effort, psychological as well as material, will, however, be necessary in order to make these advances. The means of establishing the maximum overhaul periods and keeping them right up to the maximum as experience grows, and the means of establishing the fatigue life of components and, even more, of assemblies, are, I believe, very imperfectly understood. I do not say necessarily that the details of the process are misunderstood, but that the implications are not understood. The civil and military airworthiness authorities, the constructors and the users (mainly the Government) who have to invest the money in order to save money later, will have to be asked to stretch their powers of reasoning to the utmost in order to make real advances possible.

Considering, say, a 30-passenger twin-engine helicopter, what is the background of experience that we should look for before taking the risk of passenger operation over cities? I think our S-51 provides a reasonable standard. The experience of Los Angeles Airways in America, who have flown several of these machines for approximately 3,000 hours apiece, seems to indicate that they are reasonably safe. That is not conclusive proof, but it does set something of a standard. The job of the Airworthiness authorities, managements and designers, will be to consider how experience of that magnitude is to be compressed by means of reasonable test procedures within the bounds of economic possibility and within a reasonable compass of time.

I hope that what I have said will give some assurance that the constructors do pay very close attention to operators' problems and that they have every intention of giving the best possible service.

Mr. F. L. Hodgess (*Member*): I feel there is not a great deal left to say, after the excellent contributions of Mr. HAFNER and Mr. FITZWILLIAMS; but I would like to emphasise one or two points.

I think one of the biggest factors today in the production of successful helicopters is the efficient testing of component parts. There seem to be two schools of thought, although they are not entirely opposed, because both seem to be arriving at the same end.

The first says that we should fly as many aircraft as possible loaded first with ballast and later with freight or mail until a sufficient number of hours have been accumulated to justify our confidence in carrying fare-paying passengers.

The other school of thought, which is equally important, is that we should apply fatigue tests to the component parts—flying controls, rotor head, gear boxes, clutches, transmission and particularly rotor blades—so that we are always one jump ahead in flying time of the helicopter fitted with those particular components.

Mr. FITZWILLIAMS' Company are fortunate in having a helicopter which has been tested very thoroughly in America. They are able to say that their products have behind them many thousands of hours of flying, providing evidence that, with reasonable luck, passengers could be carried to their destination without any harm. But others in this country are not so fortunate in that respect; they are starting from scratch. We could not produce helicopters during the war in this country, and we are now trying to catch up.

There is only one way in which we can test reasonably the airworthiness of our aircraft, and that is by bench and fatigue testing, following that up as quickly as possible by actual flying tests. I do suggest that in future we should follow the excellent example already started by the Bristol Aeroplane Company, of always being a jump ahead by fatigue testing.

Obviously a most important and most difficult problem is that of testing the rotor under the most severe flying conditions. There again the Bristol Aeroplane Company have set a very good example, and they have used and are using their testing tower to the best advantage. But I cannot help thinking that, good though it is, the method of sending up a pilot to test a helicopter under certain conditions while having the blades strain gauged, and then to reproduce the conditions in the tower so that the strain gauges are registering relatively the same stresses does not provide the complete answer. The de Havilland Company, for instance, have made many hundreds of fatigue tests on precisely the same item, the roots of the blades, and they get scatter in the results, even under identical conditions. In his paper Mr. Cooper has stressed the great scatter that one can get in fatigue test results.

So I would ask, where are we? I would ask designers how much fatigue testing should be undertaken on individual components, and how many identical components should be fatigue tested, before we are satisfied that any particular component can be put into a helicopter and flown with complete trust? It is a very big problem. At the same time, of course, we shall be flying our aircraft on test flights, but we cannot wait for the results of thousands of hours of flying tests. I submit that many Corporations are waiting for helicopters and would be prepared to accept them to-morrow if they were certain there were no unreasonable risks of accidents. Where can we tie up our fatigue testing with our flight testing?

One thing which Mr. Walker has illustrated and which impressed me as being very ingenious is the method of coupling gear boxes together, back-to-back, with the necessary shafting and gearing, and so on, forming a complete chain; a known torque load can be applied, and it can be run round by means of a comparatively small horse-power motor. That method seems much more elegant than to drive gear boxes having a huge brake on the end, wasting a lot of power, so that the electricity authorities may tell you next day that you cannot use it because it will shut down the power supply.

Most speakers have referred to the difficulties of tracking rotor blades on the ground, tying the machine down and having little bits of flags, and so on, to mark the blades as they revolve. I submit that there is absolutely no reason for tracking rotor blades on the ground; indeed, I consider it a waste of time. My experience is that we must track rotor blades in the air; and there is quite a simple method of doing it. One speaker has referred to the use of ordinary reflectors or mirrors on the tips of the blades, but I suggest that they can be improved, and I would mention a method which was the idea of our old friend the late F. H. Dixon. We got an Aldis signalling lamp, and with three cat's eyes of different colours mounted at the blade tips, the reflections could be seen quite well on an ordinary day. The advantage is that one can track the blades when hovering. If all is well then one can take the helicopter up to cruising speed and track the blades at the speed at which one will carry passengers with the most comfort. My experience leads me to suggest that the average rotor will not keep in track at all speeds. You can get your blades tracking beautifully when on the ground, but at the top speed of the machine they may be all over the place; the only practical way is to track them at cruising speed, and thus give your passengers the best ride.

Referring to Mr. Bristow's paper, with regard to the experience needed for a pilot to service a helicopter, I have the sort of feeling that if I were going to fly as a passenger in a helicopter I would rather fly behind a man who was originally an engineer and had learned to be a pilot, rather than a man who was originally a pilot and was learning to be an engineer. However, that is only my personal view.

Mr. K. Watson (Messrs. Cierva Autogiro Co. Ltd.—*Founder Member*) The papers to which we have listened have been very interesting and very illuminating, dealing with quite a variety of problems that are encountered every day in the helicopter. I do not wish to add to what the authors have said, but there is a point I would emphasise. We have seen in the past and in the present many helicopter configurations ; no mysterious skill is required in the evolution of a type which will fly. But the fact stands out a mile that we have now reached a stage in the development of the helicopter at which the future of the type depends on more or less conventional engineering development, which can never be a rapid process because, as scientific and engineering knowledge improves, the remaining problems become more difficult and time-consuming to solve.

I was particularly interested in Mr. Walker's illustration of the back-to-back testing of gear boxes. Personally I am very keen about such a system, but I do think it should be taken a little further and that a system of testing be evolved whereby the residual vibrations which normally occur when the transmission system is installed in the aircraft can be picked out somehow and reproduced on this rig. After all, the testing of gear boxes back-to-back will introduce only the frequencies due to tooth contacts ; we must have the others on top of these. I think we have the experience to devise such a system, and I am sure that, if such a thing can be devised, the dangers involved in carrying out so much acceptance testing in the air can be avoided.

I would add my thanks to the speakers for a most interesting and enjoyable day.

Mr. Hafner : Mr. Watson has mentioned the problem of the better representation of real flight conditions in ground rigs ; and he has referred to a gear for running gear boxes with small power. I would explain to him that we are not merely simulating the torque, but the fluctuating stresses. The conditions in flight are established by strain gauges, and we simulate what we have found to take place in flight.

Mr. Fitzwilliams : Mr. Hafner has offered one solution to Mr. Watson's problem and there are others. In our case the gear boxes are arranged as sketched (**Mr. Fitzwilliams** illustrated a set-up for running gear boxes, and showed how a set of gears was connected to input and output shafts) and, because there is a gear ratio between input and output shaft, if we twist one gear box and hold the other still, this automatically torques up the whole system. This is done hydraulically on our test rig and it is obvious that with a hydraulic system you can induce any pressure (*i.e.*, torque) variation you like.

Mr. C. W. George (Metallurgy Department, Royal Aircraft Establishment) : I would mention first that my association with helicopters, Autogiros and aircraft of all kinds is in trying to provide better materials of construction, to examine failures of all kinds and to see whether we can prevent such failures occurring again. With that in mind I would like to say a few words to designers.

From my examination of various components I have been amazed and appalled by some of the designs, which seem to indicate, shall we say, the lack of a little careful thought. It seems to me that in many cases the designer completely ignores fatigue ; he designs on static strength and, if he does think of fatigue, he will say that it is not very much and that he will allow a little for it. But he does not allow enough. If he does think of fatigue he may forget other things, such as the finish of a part where the stress is highest and where " stress-raisers " can arise from all sorts of things. The old trouble of insufficient radius of fillet is probably the most common ; and if he is a good designer and decides to provide a good fillet, the machinists may let him down and, instead of providing a nice smooth fillet, blending smoothly into the sides, they make one which finishes with a step. I have even seen radii which have consisted of a series of steps.

Those things are sometimes the cause, not only of minor accidents, but of catastrophies. Some people will say that it is very easy to be wise after the event ; but a lot of the trouble can be avoided by the application of a little thought in machining in the first place. Designers are often at loggerheads with the production people, who say they cannot do better, or that it will cost another twopence or threepence apiece. But it is well worth that small extra cost if it will avoid the loss of an aircraft.

I would therefore ask designers and machinists to think about these matters. I would ask the designer to appreciate that there is bound to be vibration on every part of any aircraft—and therefore each part must be undergoing fluctuating stress, of some magnitude. If there is a fluctuating stress it is his job to consider what is the maximum tension stress in the part concerned, and that is where he should concentrate his efforts. If he has any doubt at all he should get someone to check it. Having done that he should consider whether, if it fails, the result will be catastrophic ; and if so, he must give it more thought.

If you agree that it is very necessary to prevent fatigue failure—and even after applying your best efforts you sometimes cannot forecast the fatigue stresses accurately you have to keep a check on things in flight by periodic inspection. We have heard from some speakers that periodic inspection is very tedious and is generally a nuisance. Nevertheless, I think it is very necessary, because although a part may appear to be quite alright, due to fluctuating stress, it has not an infinite life. You cannot cater for scatter. You may have a number of things which are all machined exactly similarly, or you think they are, but one of them may have just that extra stress-raiser which will let you down. I can quote a case where, years ago, among some 40,000 con. rods we had only one fatigue failure ; a combination of small factors just allowed that rod to fail by fatigue, whereas all the others went through their lives without failure. That is one of the reasons why you must continue to inspect vital parts periodically, parts which, if they fail, may mean the loss of your aircraft.

There are various methods of doing that. For steel, magnetic crack detection is probably one of the best ; but I warn you that you can easily miss cracks at the bottoms of threads and in like places. By means of a low power microscope, of about 20 magnifications, I have found cracks in things which have been passed as O.K. after examination by the magnetic crack detection method. That is because the cracks and adjacent surfaces are covered with magnetic ink ; if you can clean the part properly and put it under a microscope you can detect the finest cracks. If there is any doubt, etch it. A very simple method is to use 1 or 2% of nitric acid in alcohol or methylated spirit, both for steel and non-ferrous metals, thereby attacking not only the top surface but also the crack walls, making the crack wider and therefore more visible.

The fluorescent medium works in many cases, but you can be misled by it. When the anthracene medium was introduced, many years ago, we had some samples which had developed fine surface cracks in service and when we sent the samples to the firm concerned they just could not find the cracks with this fluorescent medium. The reason is that sometimes there are cracks which close in so tightly on the surface that you cannot get the medium into them ; normally you have to wipe off the surplus medium from the surface in order to reveal the medium-filled cracks, and in doing so in close crack samples, you wipe off the whole lot. Therefore I would not be too sure about any of these fluorescent media being infallible.

Similarly, with regard to crack detection down the sides of weld fillets you can be misled. I think the best thing to use is a low power binocular microscope.

The paraffin and chalk method for non-ferrous and ferrous parts is very good. You immerse the part in hot paraffin and then take it out and wipe it quickly, but cleanly, and blow on fine white chalk ; it is one of the best *simple* methods and it is used by many firms.

In addition to examining for cracks, you should also look for evidence of " attrition," which can be very serious. We have had examples in fatigue tests where shackles have failed at fatigue stresses only one-fifth or one-sixth of that which the material will stand normally ; those failures have been due to local friction, which causes not only slight roughening but probably decarburisation as well in the case of steel. I advise that if you see a little " blueing " or roughening you should clean it out, even at the expense of reducing the section by a few thousandths of an inch, because if it is left the fatigue life of the part will certainly be reduced.

Another matter is the use of high-strength alloy steels and light alloys ; you have to treat them with much more respect than the ordinary mild steels and medium carbon steels. High-strength light alloys are bound to have high internal stresses, and if those high internal tension stresses reach the surface where there is applied high tension stress, then instead of starting from zero tension stress you are starting fairly high up the scale. It is for that reason that shot-peening, nitriding, etc., which induce compressive stresses, are generally beneficial ; it is generally accepted that nitriding will give you an improvement of 25% on plain specimens and as much as 300% on notched specimens.

Again, there is the liability to produce the crazy-paving pattern of cracks by rash grinding, these cracks providing starting places for fatigue cracks. With nitriding, that does not occur so readily, but you have still to remove that very thin coating of decarburised material. If you do grind you must use such a light cut that you do not run the risk of forming crazing cracks.

It has been mentioned by one speaker, I think it was Mr. WALKER, that in fatigue tests on rotor tie rods he applied a particular stress 10 million times or so, then increased the stress to a much higher value and had a very long run. But he must be careful not to be misled by that. There are such factors as " understressing " and " overstressing." If you first apply a load which is less then the normal fatigue limit stress for (say) 2 million times, then increase the stress and apply that for another 2 million times, and so on, you can ultimately get a stress 25% higher than if you applied the normal fatigue stress for 10 or 20 million times. Similarly, if you apply about 6% extra stress for one-fifth of the normal fatigue life, you can then run up and get the material to stand a very much higher stress. You may think you have something which is very safe, whereas if you run it very close to the fatigue life stress of the material you may get a failure, not necessarily at 10 millions, but even at 15 millions.

My whole purpose is to try to make aircraft safer, and I do hope that my remarks may give rise to a little more thinking about these matters.

Mr. W. E. Cooper (Fairey Aviation Co. Ltd.—*Member*) : I should like to thank Mr. HAFNER in particular for his very nice remarks. I agree with him to a certain extent about the relative values of timber and metals, but the whole point is that, if you have no notches at all in your timber structure, you can use it ; and I do feel that in ordinary propeller work, as there is usually adequate radiusing, coupled with bulk of material, there is a good factor of safety covering the notch sensitivity embraced by timber materials.

Before the war, when we were more interested in ordinary propellers than we are today, we carried out a programme of fatigue tests, including mahogany and impregnated woods as well as light alloys. But in nearly all our fatigue tests with timber materials, the specimens broke at the wide end of the shank, where the stress should have been very much less, simply because of their notch sensitivity. We were so disappointed with this feature that we decided that metals were safer materials.

Mr. A. Bristow (*Member*) : I have been singled out for a colossal attack which I never expected ; maybe I have been speaking above your heads ! That is because I am speaking of machines with which you have never had the chance to gain experience, but which are far in advance of anything that exists in this country. I hope you will take that seriously. Perhaps you have not quite understood me.

I have no real criticism of the technical points which the various speakers have brought out. But a tremendous amount of emphasis seems to have been laid on this tracking business. I am a little worried because, as Col. HODGESS has said, tracking can be done in flight, and I advocate it 100%. We have found that the Hiller, being so vastly superior to any other, does not need tracking—at least, only on very rare occasions !

References have been made to ground equipment, and Mr. HAFNER has asked for a compromise. There can be no compromise for the operator ; because he has no option to buy a cheap or relatively cheap machine, he has to pay fantastic sums for machines which will carry a very low pay-load. You must give him something that he can use. There is the point about incorporating platforms, and the necessity for certain basic pieces of equipment such as balance rigs, and so on ; but I ask you as manufacturers to build a helicopter which does not need so much of this equipment. Somebody has said there is something special about the " Hillercopter " because it has no outside. Well, it does not need it ; it works remarkably well without any outside.

Then a point was raised concerning the means of attachment of rotor blades, and I was particularly interested in the Bristol design of the four-blade tie rod. The Hiller incorporates a system of tension torsion bars having 42 leaves. By employing the tension torsion bar blade retention system in the main rotor and tail rotor systems the transmission stresses are transferred not only to the outer portion of the hub, but to the centre of the hub, which is the strongest part of the hub. That is very important, and I am glad this country is following that line.

Mr. J. D. Hayhow (Airborne Forces Experimental Establishment —*Associate Member*) : Speakers have flogged the tracking horse this afternoon. I have had to deal with most helicopters. We used the Dragonfly for over 100 hours and did not need to track it. We have had the American S-51 for some time and it has not been necessary to track. In the case of the Sikorsky 4's and 6's we track as and when necessary, usually 30 hours as the minimum, but often 60 hours and maybe more. The Bristol 171 was reasonable until we came across a small snag with the blades ; but the firm fixed that up, and we have had no further tracking trouble. In the case of the Bell we had to repair a small portion of one blade, after which no tracking adjustment was necessary.

Mr. Shapiro (*Founder Member*), who was invited by the Chairman to sum up or to direct attention to salient points which had been brought out during the day's discussions, said : My task is somewhat simplified by the fact that we have had a great deal of very interesting information today which is not strictly concerned with maintenance.

It is quite obvious that fatigue is uppermost in our minds, and it is a matter which concerns everybody ; including maintenance engineers, but I will not attempt to summarise those aspects of fatigue which do not directly concern maintenance.

The problems of maintenance as they have appeared today would seem to divide into (*a*) organisation, (*b*) technique, and (*c*) inspection. Each one of these categories, of course, has something to do with design. But design is not in iteslf a problem of maintenance ; conversely maintenance is a problem of design which strives to reduce or to control maintenance work.

On the question of organisation, references were made to the block and the progressive systems. It was said that progressive maintenance is the more or less obvious choice of the scheduled operator, whereas block maintenance is the fairly general choice of non-scheduled operators.

The second and very fundamental question is the conception of declared life. Today it was presented as a universally accepted conception ; but it has not always been so, and it need not be so. I do not disagree with it, but I put it as a matter which has its pros and cons. A declared life does not mean the true life of the component concerned, but its " Statutory " life. We may have to decrease the life of a component sometimes in order to improve organisation, and it is a question of standardising a system of lives. I emphasise that it is a question of organisation and not necessarily a technical problem.

The provision of spares is again a problem connected with the organisation of maintenance. It is not only a matter of deciding on the irreducible minimum necessary for the operation of scheduled or non-scheduled services, but there may be a wide margin, which is to some extent a matter of choice, so that the system can be adjusted to the particular organisation. I was really glad to hear that there is a figure, being about 35% of the cost of the aeroplane, which will be sufficient to provide the full schedule of components for progressive maintenance.

The question of training has been mentioned ; it was said, and I think it was very well put, that a man who has no experience himself cannot examine that of someone else.

I think the problem of standard components divides into two stages, that of standard commercial components, and that of ancillary equipment which is standard in aircraft. Some speakers went further than others in wanting standard components suitable for motor car use as well. I think the concensus of opinion is that we want standard aircraft components and ancillary equipment where possible, but that to standardise equipment for use in both motor cars and aircraft would mean going too far.

I would emphasise that experience in maintenance enables us to select details for attention. Again that is a matter of organisation, of devising manuals and instructions, so that essential details are really fully dealt with.

Now we come to technique, and, personally, I feel that many of our members who have been dealing with these jobs have been rather shy of discussing them in detail, although that is what we really came here to listen to. References have been made to accessibility, which is universally accepted as being desirable ; and it has been stated that it can be achieved if everything is put outside, or if there is no outside shell at all.

In connection with engineering tolerances some figures were mentioned, such as tenth of a thousandth of an inch. It was felt that means should be provided to enable us to avoid using such tolerances in *assembly work*. A ball-bearing, for instance, with really fine tolerances, can be put into a housing, but the housing is mounted with less exacting tolerances.

It was said that locking methods could be improved from the maintenance point of view, and various details have been mentioned, such as the use of tab washers and other locking methods which are less time-consuming than split-pins.

There have been conflicting views concerning the extent of the ground equipment necessary, ranging from the elaborate equipment which it was said would be the fairly obvious choice of the scheduled operator, who would do most of his maintenance and servicing under suitable conditions in well-prepared workshops, to the requirements of non-scheduled operators who have to do their maintenance work under very unsuitable conditions and have to cart their equipment about. I think there must be different arrangements for different jobs.

It was said that tying-down facilities must be provided on helicopters in order to improve certain methods of rigging, but, I think, that was a solitary view. On the other hand, others have emphasised the need for tracking after every flight, and it has been said that methods are available which are satisfactory and easy, and also very cheap.

I rather missed references to lubrication and the use of materials for that purpose, and also to the use of methods to afford protection against corrosion. We have not had any detailed discussion on these matters, but perhaps they will receive attention in the future.

It is in connection with the third heading, that of inspection, that most of the information on fatigue is of real importance to the maintenance engineer. Several methods of surface inspection were mentioned, such as the magnetic method for ferrous alloys, the ordinary oil and chalk method for aluminium alloys and some of the proprietary methods using fluorescent fluids. The defects of these methods were discussed, and some very important points were made concerning the need for observing evidence of corrosion and attrition (a form of fretting), which I think maintenance engineers should take very much to heart. I think these points are some of the most important in respect of helicopter maintenance.

If I may again voice my own opinion, this problem of surface inspection should receive further attention. The choice of materials affects the maintenance engineer. Some materials are more easily inspected than others and are not so treacherous, and the maintenance engineer would prefer to work with materials which are not quite so sensitive to faults in heat treatment, and so on. Forms of surface treatment have been mentioned, such as nitriding, shot-peening and so on.

There are other points concerning inspection which have been discussed, such as balancing and tracking ; I think those who have attended today will remember the wide diversity of opinion on the latter point. The problem of providing ground running rigs is perhaps a little outside the field of inspection or maintenance ; it concerns mainly the designer and the manufacturer rather than the operator.

We have enjoyed a most interesting and fruitful discussion.

The Chairman: We have reached the end of our day, which I am sure we have found both instructive and interesting. I hope this discussion may perhaps prove to mark the beginning of a series of similar discussions arranged periodically on maintenance and, indeed, on a variety of subjects of importance to helicopters generally.

Mr. N. J. G. Hill (Chairman of Council, The Helicopter Association), who was invited by Mr. McClements to thank the speakers, said :—

It seems that today we have dispelled a number of illusions. For instance, it has been suggested that although able to fly quite well certain pilots appear to be incapable of reading or writing when on the ground. Maybe it has something to do with the effect of vibration Then there was the suggestion that maintenance engineers, especially when in the presence of pilots or designers, find themselves inarticulate and quite incapable of expressing their thoughts. Then there is the view that all chief designers are pig-headed morons who put themselves behind closed doors and blacked-out windows to produce drawings and specifications beyond the understanding of anybody else.

Today's discussions have fairly shown, I think, that those illusions are dispelled.

I should like now to say, on behalf of the Helicopter Association, how much we appreciate the work which has been done by Mr. Hardingham, Mr. Murray, Mr. McClements, and their associates, and by the contributors to the discussion. The very high standard of the papers presented is an indication of the enthusiasm of both bodies, and the manner of the delivery has been excellent. I think the future holds for us many similar happy meetings. An immense amount of matter has been covered today and none of us can expect to deal with it in four or five minutes. When we have seen the results of the work in print we may well consider another meeting, perhaps four, five or six months hence, at which we can, in the light of the knowledge gained by that time, discuss further these subjects which are so interesting to us.

I know you will wish to join with me in applauding the work which the organisers of this meeting have done, and I invite you to do so now.

(The vote of thanks was accorded with enthusiasm, and the meeting closed).
