to use a very small horse-powered motor sufficient to overcome friction to drive the rig.

It is hoped that by keeping ahead with the number of hours run on a rig of this nature, compared with those flown in any production machine of the same type, it will be possible to anticipate any gear or bearing troubles due to fatigue before they are due to occur in the aircraft itself.

The testing of rotor hubs and blades (both main and tail) follows the same procedure as that for gearboxes, the prototype unit being spun on a test stand for a greater number of hours than any similar production unit has flown.

It has not been possible in this case to reduce the power required to drive the rig, but testing may be carried on day and night without danger to personnel.

It is more difficult to ascertain the stresses imposed in flight under the various operational conditions on rotor blades than in the case of the transmission. For this purpose a prototype set of blades is fitted with strain gauges at suitable points over the whole area of the blade. The strain is then recorded in flight at each of the required conditions. The rotor is then removed from the aircraft and mounted on the rotor spinning tower and conditions adjusted until the same readings are produced on the strain gauges as those observed in flight under the conditions it is required to simulate.

The other main component of the rotating parts of a helicopter is the engine. Although this is a complex component and is subject to fatigue loading in the same way as the transmission, it is not considered to be a critical part. In the event of engine failure there is no loss of control and an autorotative descent may be made.

For this reason is it not considered necessary to investigate extensively the fatigue life of each item, the testing covered by the type test running being considered adequate. It should be noted that it is often convenient to mount a radial engine on its back, *i.e.*, with its crankshaft more or less vertical. It is considered desirable that the engine be calibrated in this position and as the normal type of dynamometer is only satisfactory with its shaft horizontal, it is necessary to pass the power through a right-angled gear box. This procedure is not entirely satisfactory as the dynamometer records the power of the engine, less the friction in the gear box.

I would like to conlcude by saying that I think component rig testing is essential in the development of helicopters. The work may, of course, be carried out by the test flying of the complete aircraft but, besides being dangerous, a test programme which can be covered by a few weeks of day and night running on a test rig, will require months, if not years, to complete by test flying.

PAPER

By MR. F. L. SWAIN (Messrs. Westland Aircraft Ltd.).

THE CHAIRMAN : Mr. SWAIN was trained as a metallurgical engineer at the County College, Staffordshire, and has served for 15 years with the Westland Company. Of that 15 years he spent 11 years on inspection, and another 3½ years as Service Engineer on Westland-Sikorsky helicopters. He is one of the few engineers who has his "A" and "C" licences for the helicopter. He is now Senior Service Engineer to the Company.

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AN ANALYSIS OF PRESENT-DAY HELICOPTER MAINTENANCE

By F. L. SWAIN.

In preparing this paper it was obvious to the writer, from a perusal of the titles of the other papers arranged for this meeting, that some of the subjects discussed will have been dealt with in some measure by previous speakers, as this paper also deals with the Westland-Sikorsky S-51 helicopter. Where such repetition occurs the writer tenders his apologies.

The Westland Sikorsky helicopter is well known in this country through its commercial activities over the past three years, and more recently its application to the Navy and R.A.F., whilst its American opposite, the Sikorsky S-51, has accumulated many thousands of flying hours to its credit, proving that the design has dependability and adaptability for the many roles of operation it has to meet. A close liaison between the American and British makers ensures the best possible service to all its operators.

The Westland-Sikorsky S-51 inherits to a large degree the same qualities as the American model, and in discussing its maintenance many of the practices used are common to both models.

There are a large number of systems used in this helicopter that are very similar to those used in the conventional type of aircraft and for which standard maintenance procedures are laid down. It is proposed, therefore, owing to the time factor, to discuss only those units and assemblies peculiar to this helicopter.

To commence this analysis of the S-51's maintenance, an examination of the inspection periods laid down on the maintenance schedule will provide the framework on which to build the maintenance procedure.

TABLE NO. 1.

INSPECTION PERIODS FOR WESTLAND-SIKORSKY S-51 HELICOPTER.

Preflight.		
Check 1	After	5-10 hours' flying.
Check 2	„	25-30 „ „
Check 3	„	50-60 „ „
Check 4	„	100-120 „ „
Check 5	„	200-240 „ „
Check 6	„	400-480 „ „
Check 7	„	2000-2400 „ „

A glance at these inspection periods will show that they closely follow those of the most conventional type of aircraft, and the introduction of the check system brings the inspection of the helicopter in line with the general practice now used in the aircraft industry. Inspections up to 100 hours' flying are not lengthy procedures and call for no special requirements, but at the 100-hour flying period and at 100-hour cycles major unit overhauls are required. These are shown in Table No. 2.

TABLE No. 2.

TYPICAL UNIT OVERHAUL PERIODS.

Unit.	*Overhaul Periods*
Clutch and Fan	After 100 flying hours.
Main Rotor Hub ..	„ 200 „ „
Tail Rotor	„ 200 „ „
Intermediate Gear Box ..	„ 200 „ „
Rotor Head	„ 400 „ „
Main Gear Box	„ 400 „ „
Engine	„ 400 „ „
Tail Rotor Gear Box ..	„ 600 „ „

It will be observed that these overhaul periods vary from 100 to 600 flying hours. This variation requires explanation, and a review of each unit's history will provide the reasons for this disparity of unit overhaul periods.

The necessity to overhaul the fan unit after 100 hours' flying was caused by the failure of the American design of fan blades (*i.e.*, cracking at the root attachment to the fan disc) when used with the Alvis engine. The cause of this failure was traced to fan blade resonance, *i.e.*, the critical resonance of the blades was occurring at operating engine speeds. The introduction of thinner fan blades overcomes this fault, for they permit the critical blade resonance to occur at engine speeds below those at which the engine normally operates.

The introduction of the new blade design has, however, to be proved in actual operation, as well as by ground and flying tests, and although the latter have given good results Service experience must also prove that the new design is satisfactory.

When these requirements have been met an increase in the fan unit's overhaul period will be given in 50-hour periods until it reaches the power plant overhaul at 400 hours. The maintenance now necessary on the fan unit is the removal and crack detection of the blades after every 100 hours' flying.

The crack detection of the main rotor hub after 200 hours' flying has been standard practice from the beginning of the manufacture of the helicopter in America—the original design having a fixed life of 300 hours only. A re-design was effected approximately two years ago which increased the wall thickness of the hub arms and revised the method of torquing the flapping link retaining nuts, and after exhaustive tests the hub was given a fixed life of 2,000 hours, with crack detection at every 200 hours. American experience has now been responsible for fixing the life of the hub at 840 hours.

There is no record of any faults having been found in British hubs made to the latest American design. We are, however, guided by American practice and therefore crack detect the hub after each 200 hours' flying.

The overhaul of the tail rotor and intermediate gear box after 200 hours is to effect crack detection of

(*a*) the two gears in the intermediate gear box ;
(*b*) the side plates, spindles and hub of the tail rotor.

These particular parts have proved highly satisfactory after many overhaul periods and are now approaching the time when consideration can be given to an increase of their overhaul period.

To reach an overhaul period after 400 hours' flying, as in the case of the rotor hub and main gear box, is an achievement which is envisaged for all major units of the helicopter, thereby creating one major overhaul period for airframe and all major units. Satisfactory Service experience will, however, increase the overhaul life of the rotor head and gear box still further.

The tail rotor gear box with an overhaul period after 600 hours' flying has been developed for many years. The design has been in use on very early Sikorsky models, and only after thousands of trouble-free flying hours has it been possible to reach this overhaul period.

In concluding this examination of the overhaul periods laid down for major units, it should be emphasised that Service experience after exhaustive tests is the only positive method of fixing overhaul periods for any components, and therefore the development of new designs must present this problem of overhaul for the helicopter's units.

An alternative method will be for the prototype aircraft to carry out hundreds of flying hours in proving these units, and in the development of large passenger-carrying helicopters such methods will have to be adopted.

Having briefly discussed the reasons for the fixing of the overhaul life of major units, an examination of the special equipment and procedures used for this purpose will show that neither are complex or highly expensive.

Crack detection plays an important part in the overhauling of many helicopter assemblies, and parts requiring this inspection may either be returned to the manufacturer, forwarded to the nearest approved helicopter overhaul unit, or effected by the operator himself after purchase of the necessary plant.

The first two methods named will probably involve delays, while the purchase of the plant would ensure immediate attention when required, and as it will be a recurring process the initial cost will soon be off-set by time and expense saved.

There are two methods at present in wide use :

(*a*) the magnaflux method for ferrous parts ;
(*b*) the glow crack method for non-ferrous and light alloy parts.

It is not proposed to discuss these methods in detail, except to state that their operation presents no difficulty after a little experience and that guidance in this subject is given in the helicopter manufacturer's overhaul manual and by the makers of the equipment themselves.

The practice of crack detecting parts is a common one in the aircraft industry, and in helicopter manufacture and maintenance has become universal. The satisfaction and assurance given to manufacturer and operator alike, coupled with its simplicity of application, are likely to lead to the adoption of this inspection procedure in the helicopter industry for a long time to come.

Having discussed the first of the special equipment and processes required for the maintenance of the S-51 helicopter, we pass on to the subject of special tools. These are few in number and have been designed to simplify the helicopter maintenance in the dismantling and re-assembly of units. Their development over the past four years has been progressive to meet the requirements of both operator and manufacturer, and consist of extractors, special spanners, engine removal equipment and balancing equipment. The last-named item, balancing equipment, is not an elaborate structure but a simple stand in which the tail rotor and fan assemblies may be balanced and tracked after overhaul. The special equipment previously outlined is all that is required to carry out a complete overhaul of the helicopter, the amount and cost comparing favourably with that required for modern aircraft of the same weight.

One very important part of efficient maintenance is that of spares provisioning, and this section of helicopter maintenance could well be the subject of a complete paper, for operators' needs will vary in proportion to the number of aircraft used and the type of work on which they are employed.

To cover operators' initial requirements, a minimum standard supply of spares for the first 400 hours' flying is sold with each helicopter.

There is, however, one important section of spares provisioning which is considered worthy of mention in this paper, and that is the use of spare major units to permit a rapid change of units on the helicopter when their overhaul period is reached.

When a unit on the helicopter is due for overhaul it is necessary to remove it for the purpose of dismantling, inspection and re-assembly before it can be re-installed for further service. The time taken for this work varies with different units and is quite considerable at the airframe overhaul period at 400 hours when, in addition, all major units become due for overhaul. Each time an overhaul is necessary the aircraft is grounded until its completion. This grounding of the aircraft for complete unit overhaul reduces its earning capacity.

To reduce this time the aircraft has to spend on the ground, the unit change system may be adopted, and to illustrate its application a unit of three helicopters operating on regular daily work is described.

It would be normal practice, therefore, to have two helicopters on full operation and the third as a stand-by in the event of trouble, so that at all times the three aircraft must have the maximum possible serviceability. To ensure this, spare units (1 off each as listed in Table 2) must be available.

When a major unit reaches its overhaul period its corresponding spare is used as a replacement, while the unit for overhaul is removed to the overhaul department to be prepared for the next aircraft.

To ensure sufficient time-lapse for this work, the flying hours of each aircraft should be staggered. In this way a constant flow of units for overhaul is maintained, and are available when required. At the first airframe overhaul, *i.e.*, after 400 hours' flying, the stand-by helicopter is placed into service whilst a complete set of overhauled major units are fitted to the helicopter under overhaul. These major units removed are then overhauled in the order of priority.

It has been estimated that a reduction of approximately 38% of the normal man-hours required for a major overhaul can be achieved by fitting serviced components, at the same time avoiding intermittent periods of

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idleness and overwork for ground staff, and permitting a steady flow of overhaul work.

It is our practice to issue Log Books with each major unit so that as each unit is replaced from time to time on different helicopters a complete history of the unit can be maintained. The efficiency of this system of unit change will depend on :

(*a*) the organisation of the overhaul department to meet the demands for units ;

(*b*) the availability of minor spares for servicing major units.

Experience has shown, however, that the system can be used to good effect and indeed, with a small unit, is necessary where every flying hour affects the economics of the operator's business. The cost of purchasing the major units listed is 34.4% of the purchase price of one helicopter, which over a period would more than warrant the outlay by permitting increased earning capacity of the whole fleet of aircraft.

It would appear that this method will become standard practice for operators using small numbers of helicopters for some time to come, for the fixed life major unit is not yet a possibility—economically or mechanically. Future design will, therefore, demand increased ease of accessibility and removal of major units to make unit changes an even simpler and more economical operation.

Lubrication of the Helicopter.

The correct and regular lubrication of this helicopter forms a most important part of its maintenance, and failure to observe the manufacturer's instructions has on several occasions in the past necessitated replacement of bearings after only short periods of operation. Service experience has shown that care of this simple operation pays handsome dividends in the form of long life to all components needing its application.

This analysis would be incomplete without reference to the maintenance engineer. At present, and probably for a long time in the future, the helicopter demands the attention of skilled engineers at all times. To ensure that the maintenance of the Westland-Sikorsky S-51 is carried out by such engineers the manufacturers have set up a school where experienced aircraft engineers can be trained in helicopter maintenance. A six-week comprehensive course has proved, in most cases, sufficient to enable such engineers to undertake full maintenance duties of the helicopter.

After one year's experience in these duties, he is eligible to obtain the A.R.B. Maintenance Engineers' " A " and " C " Licences covering the particular helicopter type.

Similarly, engineers with previous helicopter experience may take a conversion course lasting three weeks on the S-51 helicopter.

The creation of such a school ensures that the helicopter will be serviced by competent personnel, a necessity in this young industry and upon which its future development depends so much.

It is the desire of the manufacturers to co-operate to the fullest possible extent with the operator, for indeed only by such co-operation can the present

and future needs of the industry be met, the future designs be planned, and the existing design be improved.

As part of this co-operation, we issue from time to time, as they are required, Service Circulars to all operators of the S-51. These Circulars contain information which assists the operator in many ways, either in the form of improvements to a part to give added life, the design of a new tool to improve servicing, or maybe information concerning a fault. These Circulars are often issued as a result of information received from our Associates and much valuable information is circulated in this way.

The operator in return is requested to send to the manufacturer a monthly report sheet on the behaviour of his helicopter, and with this liaison a complete and regular service between operator and manufacturer is maintained.

It is hoped that in listening to this paper you have gleaned a little of the ways and means by which the Westland-Sikorsky S-51 helicopter is maintained in service, although each subject has been treated briefly.

Helicopter maintenance generally will advance automatically with design. Simplicity in design usually means simplicity in maintenance, and in the building of bigger helicopters much attention will have to be given to their maintenance. However, much advance has been made in the past years, and reviewing this advance with reference to the S-51 helicopter we find the following :—

Inspection Schedules have been brought into line with those used in the aircraft industry, component overhaul life is increasing, inspection methods are efficient and special equipment is not excessive, the unit change system ensures more available flying time, skilled engineers are increasing in number, and liaison between manufacturer and operator is established. All these assets are necessary to permit planned operations commercially and in the armed forces, and provide an essential basis for future helicopter operation.

PAPER

By MR. W. E. COOPER (Messrs. Fairey Aviation Co. Ltd.).

THE CHAIRMAN : This is a most important subject, and Mr. COOPER is very well qualified indeed to write the paper. He is a Fellow of the Royal Institute of Chemistry, a Fellow of the Institute of Metallurgists, a Member of the Institution of Mechnical Engineers and a Fellow of the Royal Aeronautical Society. He was trained at Birmingham University and the Central Technical College ; he was Head of the Metallurgical Department of Messrs. Guest, Keen and Nettlefold, Birmingham ; Chief Metallurgist, Messrs. R. A. Lister and Co., Dursley, Glos. ; and is Chief Metallurgist of the Fairey Aviation Co., Ltd., having been there since 1936. He has been Chairman of the S.B.A.C. Materials Committee for more than eight years, and is a member of various B.S.I. committees.

Unfortunately, he is not with us today, and we are grateful to Mr. HODGESS, of the Fairey Aviation Company, who will present the paper.