ACCESSIBILITY, SERVICING AND TESTING OF COMPONENTS

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Prototype helicopters at the Bristol Aeroplane Company have been produced and servicing schedules have been made up detailing the maintenance work and inspection that has to be carried out after the following periods : (*a*) between flights, (*b*) daily, and (*c*) after 30, 60, 120 and 240 hours flying.

At the time these schedules were made it was not fully realised that the work would not be carried out exactly in this way.

We now learn that the airline operators are dividing their 30, 60, 120 and 240 hour inspection and maintenance schedules into small parts. One of these parts is added to the routine daily inspection, and so, by the time 240 hours of flying have been completed the whole of the interim schedules have also been completed, without withdrawing the helicopter from service. This system can only be operated providing that all work in the schedules can be split into tasks of less than, say, three hours each ; there must, of course, be exceptions as obviously the overhauling of an engine takes longer than three hours. It will be the practice for the operator to hold a spare of each of the main components which have to be overhauled as a complete unit at the rate of about one to five helicopters. Now, when the time comes for an engine or a gearbox to be overhauled it will be removed from the aircraft and replaced by the spare. The component removed will then be prepared as a spare for the next aircraft when its appropriate component is due for replacement.

It will be seen from the foregoing that the time of overhauling, say, a gearbox is not so important when considering the unserviceability time of the aircraft, but what is important is the time it takes to remove the gearbox from the aircraft and to replace with a serviced one. For this reason care should be taken in design that component mounting points are few and that transmission shafts are easily adjustable in length to suit the accumulated tolerances on dimensions between the main components.

A common source of trouble on helicopter transmissions is the leaking of oil seals. For this reason, wherever possible, oil seals should be designed in such a way that they can be removed and replaced without removal of the component from the airframe or at least without completely stripping the component.

I would like now to discuss the testing of components as it affects the manufacturer and the operator.

When a helicopter of a particular type has been designed, manufactured and developed to a stage when it is considered to be ready for production in quantity, the engine, transmission and rotors are subjected to a type test and the rest of the aircraft, such as airframe, instruments, controls, etc., are shown to be airworthy by calculations laid down in the type record for the aircraft.

The type test involves 100 hours ground running under various power loadings of the engine, 50 hours ground running of the transmission and rotors and 150 hours test flying.

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It will be seen that the total time the transmission and rotors must run to become approved as a type is only 200 hours.

Although this test will show up weaknesses in design involving the rapid wear of over-stressed parts such as bearings and gears, there are a number of rotating parts in a helicopter which are subject to cyclically imposed loads. Samples of these are the rotor blades themselves, the blade roots, the flapping and drag hinges, and the parts of the controls which rotate with the rotor hub. Some of these parts will receive variations of load at once per rotor revolution associated with a rotor out of balance, or three times per rotor revolution associated with forward speed and variation of airflow over each rotor blade, and some as high as 50 times per rotor revolution associated with the engine impulses.

These cyclically imposed loads may cause fatigue in important metal details and failure after many flying hours have been logged, although no suspicion of weakness has been evident during the type test.

It is obvious from the foregoing that a satisfactory completion by a helicopter of the type test is not sufficient to approve the aircraft for carrying fare-paying passengers. Many hours of test flying must, therefore, be carried out by the manufacturers' test pilots and it is necessary that a new type of helicopter must first fly for many hours as a freight or mail-carrying aircraft without serious defect before approval may be gained for the carrying of passengers.

Although this procedure safeguards the fare-paying passenger, the prospects for the test and freight-carrying helicopter pilots is not so rosy. It is for this reason that attempts are being made to simulate flying conditions on test rigs so that all important components can be tested over long periods to ensure a satisfactory fatigue life. This does not mean that each major component of a production line must be subjected to long periods of endurance running but that a prototype of each of the major components should have been rig tested for a greater number of hours that the total flying time of any similar component fitted to an aircraft.

The problem of fatigue life of components has been receiving attention both in this country and in the U.S.A., from whence comes a suggestion that the life of a critical helicopter part which is subject to cyclic loading and which is shown by test or otherwise to have an unlimited fatigue life should nevertheless be retired from service after 2,000 hours. Furthermore, critical parts which are shown to have a finite fatigue life should be retired from service after 75% of this life in flying time has expired, with a maximum life of 1,500 hours.

If this requirement became mandatory it would put an extra burden on the cost of helicopter operation. Since the lifetime of a helicopter is at present visualised as 7,500 hours, at least four new sets of expensive critical parts would be required for each aircraft. I might at this point say that it is incumbent upon all helicopter designers to keep the number and complexity of critical parts to a minimum, that is, those parts a failure of which causes loss of life and/or loss of control. Particular attention has been paid to this point in the design of the Bristol helicopter.

Before discussing the testing of the various components I would like to say a few words on the testing of a particular item which is unique in the Bristol helicopter, namely the blade tie rod.

As is generally known, each tie rod is composed of eight sections each consisting of a 45° segmental cross section and about 36 ins. long. The segments are first clipped together and then at each end a thread is machined on the periphery. The function of the tie rod is to attach the rotor blade to the rotor hub, one end of the rod being screwed and clamped at the drag hinge pin on the hub and the other end at the blade root. The tie rod is loaded by the centrifugal force of the blade, which is of the order of 30,000 lbs., in normal flight and in addition it has a cyclical torsional oscillation which varies between $\pm 12°$, according to the control position. This is obviously a case of a critical part which is subject to fatigue loading and it was decided to carry out a test to reproduce the loading conditions in flight. The first Fig. shows the rig with two tie rods connected end to end and the load representing centrifugal force applied. The outer ends of the rods are resisted torsionally and the small electric motor driving the eccentric

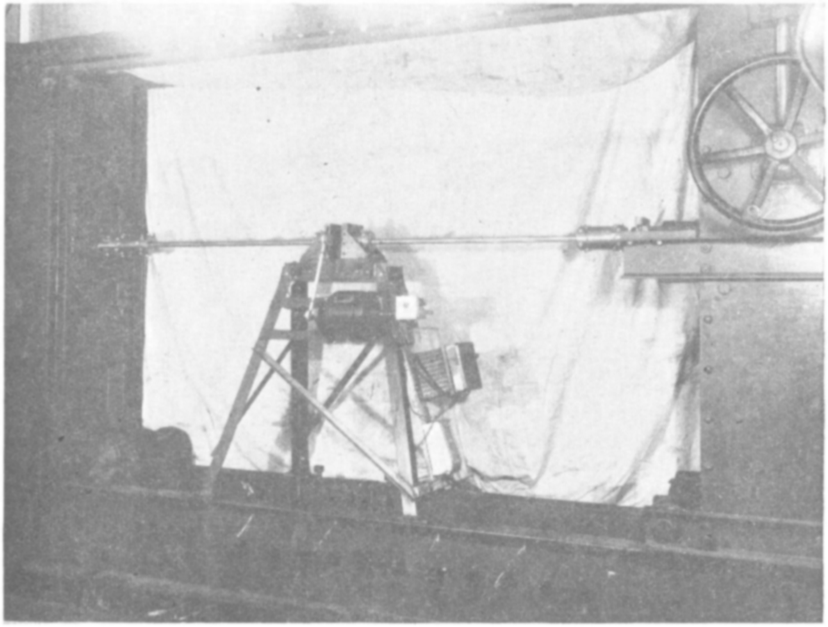

Fig. 1. Blade tie rod test rig.

turns the inner ends of the rods cyclically through the maximum range of the angle of twist encountered in flight. The power required to drive the rig is very small, as the torque needed to twist the tie rods under load is far less than that required to move a rotor blade, having an equivalent centrifugal load, in pitch, when mounted on ball or roller thrust bearings. This feature is the main contribution to the lightness of control column loads characteristic of Bristol helicopters.

The test was carried out running day and night until 20 million reversals of torsional stress had been recorded without failure of the rods. In view of the fact that ferrous materials are considered to have an infinite fatigue life if no failure has occurred after 10 million reversals of stress, the tie rods would normally be considered as " safe," for the life of the aircraft.

Nevertheless, it was decided to continue the test in view of the importance of the duty the rods have to perform in the aircraft. The end load was increased and a further 20 million reversals of stress applied. This was done three times until the rods had eventually withstood 80 million reversals of stress without failure. The last 20 million reversals were carried out with an end load of 80,000 lbs., compared with the normal centrifugal load in flight of 30,000 lbs.

I think you will agree, when considering the results of this test, that it is unnecessary to retire tie rods from service after only 2,000 hours flying, equivalent to approximately 30 million reversals of load in the test.

When designing helicopter transmissions it is necessary to estimate the life of the aircraft and also to tabulate the various conditions of operation with the corresponding power and speed loading and the % of total running time at each condition. The next Fig. shows a typical set of conditions

LOADING CONDITIONS FOR FRONT GEARBOX (OUTPUT SHAFT)

CONDITION	CASE	TORQUE 'M' LB. FT.	SPEED 'N' R.P.M.	Nº OF HOURS RUN
CRUISING MAX.	1	5,440	232	44
CRUISING 80% POWER	2	4,070	232	40
VERTICAL ASCENT	3	9,500	287	4
MAXIMUM FORWARD SPEED	4	8,600	270	2
ENGINE OFF	5	—	287	1·3
CLIMBING	6	6,790	261	4
REVVING UP (ONE ENGINE OFF)	7	5,200	287	·7
GLIDING	8	1,550	261	4
				TOTAL 100

EQUIVALENT RUNNING TIME UNDER CASE 3 CONDITIONS:—

$$t_e = t_3 + t_1\frac{N_1}{N_3}\left(\frac{M_1}{M_3}\right)^3 + t_2\frac{N_2}{N_3}\left(\frac{M_2}{M_3}\right)^3 + t_4\frac{N_4}{N_3}\left(\frac{M_4}{M_3}\right)^3 + t_6\frac{N_6}{N_3}\left(\frac{M_6}{M_3}\right)^3 + t_7\frac{N_7}{N_3}\left(\frac{M_7}{M_3}\right)^3 + t_8\frac{N_8}{N_3}\left(\frac{M_8}{M_3}\right)^3$$

$$t_e = 4 + 6{\cdot}7 + 2{\cdot}55 + 1{\cdot}43 + 1{\cdot}32 + 11 + 16$$

$$t_e = 16{\cdot}27 \text{ HOURS}$$

TORQUE AT WHICH IT IS REQUIRED TO RUN TEST RIG AT 287 R.P.M. FOR 100 HOURS TO EQUAL 100 HOURS AT ABOVE CONDITIONS—

$$\frac{100}{16{\cdot}27} = \frac{9500^3}{M_e^3}$$

$$M_e = 5180 \text{ LB FT}$$

Fig. 2.

based on a unit length of time of 100 hours for a passenger-carrying aircraft; the number of hours and conditions would, of course, vary for a freight-carrying or a crop-spraying helicopter. Gears and bearings are designed for strength on the highest loading, which is shown on the chart to be case 3, but when designing for wear conditions a calculation is made to obtain the equivalent number of hours the transmission would have to be run at this high load to produce the same wear that the 100 hours running under varying conditions would produce. As the speed of loading varies inversely with the equivalent running time and the cube of the torque varies inversely with the running time, the 100 hours of running shown on the chart may be replaced by 1,627 hours running at case 3 conditions.

On the same basis of calculation the 100 hours of running shown on the chart may be replaced by 100 hours running at the maximum speed conditions but at a new torque shown on the chart to be 5,180 lbs. ft.

It will now be seen that if a rig is built which loads up a helicopter transmission or component such as a gearbox, to the last-mentioned figures and is run for 100 hours, the wear and fatigue effect will be equal to 100 hours flying under operational conditions. To make sure that the component is satisfactory under maximum loading conditions a short period for each unit of 100 hours running is also carried out at high or case 3 loading.

The next Fig. shows diagrammatically a rig designed for the testing of helicopter main rotor gearboxes. The gearbox has a simple two-stage

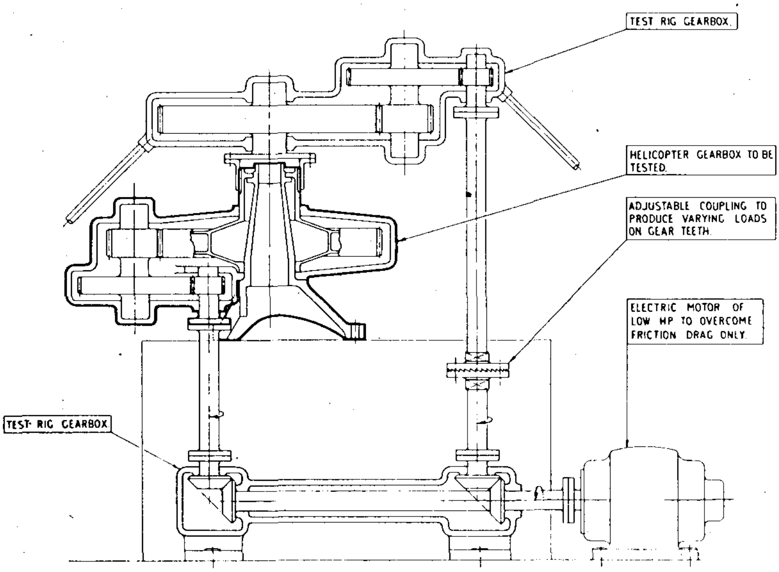

Fig. 3. Helicopter gear box rig.

reduction, the input shaft running at crankshaft speed and the output shaft coupled directly to the rotor hub. A train of gears is arranged between the input and output shafts having an identical gear ratio in the reverse direction. It will be seen that by applying a measured torque between the flanges of the special coupling and locking in the strained position all the gear teeth and bearings in the system will be loaded in a similar manner. Although the loading may be equivalent to the one previously mentioned, 100 hours of which is equivalent to 100 hours operational flying, it is only necessary

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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

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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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