Helicopter Production

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DR G S HISLOP
(*Chairman of the Executive Council*)
in the Chair

INTRODUCTION BY THE CHAIRMAN

Introducing the lecturer, the Chairman said that like other learned societies they naturally had many papers on learned subjects, on the theory of this or that and the future of this or that It was a good thing from time to time for them all to realise that they were all engaged in building or using an actual vehicle which brought many problems with it It was only right and proper therefore, that from time to time they should come down to earth and face those problems

Mr BOULGER, of the Westland Aircraft Company, would speak on the problems associated with helicopter production He had been apprenticed at the R A E , had gone to the drawing office at Westlands, and had thence graduated to the design office For a time he had been with Messrs Normalair, an associated company, and then had returned to the Westland side of the family, where he had become Chief Planning Engineer It was from his work as Chief Planning Engineer that his intimate knowledge of the production problems arose He was now Contracts Manager of the Company

MR E J BOULGER

I should start by making it clear that the views expressed in this lecture are not necessarily those of Westland Aircraft, but they are nevertheless, in the main, derived from my experience on Dragonfly and Whirlwind production when I was Chief Planning Engineer

The production of Dragonfly Helicopters commenced in the middle of 1947, the Company having decided to manufacture a batch of thirty as a private venture Manufacture of parts began in January, 1948, the first helicopter completed its hundred hour type test a year later, and the first production aircraft was delivered in April, 1949 By this date a substantial production line was running, and the aircraft has continued in production ever since

Following our initial success on the Dragonfly, the Company decided to produce the Whirlwind, and manufacture commenced in February, 1951 The first production aircraft was delivered in January, 1954, and by this time a substantial number had been completed and were awaiting Service acceptance Meantime deliveries to civil customers were being made The Whirlwind has now received a full C of A in all categories, and is in quantity production As this helicopter is our latest production effort, and may not be familiar to some of my listeners, I feel a general description would not be out of place

The centre section of the fuselage is of semi-monocoque construction, and consists of a framework of transverse channel section frames mounted on two length-wise beams in the lower structure At the rear of the centre section is a semi-conical structure, to the rear end of which the tail cone is attached The space inside the upper portion of this structure is used for baggage in the civil helicopter, or for survival equipment in the military helicopter The lower portion forms a compartment aft of the cabin rear bulkhead, which houses the radio equipment, landing lamps, battery and main electrical equipment As access to this compartment is possible from inside or outside, the installation of the radio and electrical equipment is greatly simplified for both manufacturer and customer

At the forward side of the sloping firewall, attached to the front end of the cabin, is the engine bay The engine is mounted on a ring carried on two light alloy beams, which are bolted in turn to the forward end of the lower structure, the centre line of the engine sloping down from the horizontal at an angle of 35° This arrangement has great advantages both from the point of view of production and maintenance, as the opening of the two clam shell doors at the front of the aircraft gives immediate access to the front of the engine, and the downwards slope makes it possible to carry out engine maintenance without the use of steps or platforms, the highest point on the engine being six feet from the ground

The engine installation has been arranged in such a manner that the engine with its exhaust system, cooling shrouds, etc , can be removed as a unit, and a replacement engine change unit fitted in less than two hours from " unserviceable to serviceable " By removing the upper of the two bolts which secure the engine mounting beams, it is possible to hinge the installation downwards, so as to give access to the rear of the engine and the clutch and fan unit The whole operation takes two men less than twenty minutes

The engine drive passes through the clutch, free-wheel and rotor brake to the main gear box, and thence to the rotor head

The spiral bevel gear on the main gear box input shaft drives two epicyclic gear systems with a reduction ratio of 2 8 to 1 each, resulting in a compact and efficient arrangement

The rotor head consists of a steel splined hub bolted to two light alloy star plates, the arms of which carry the flapping and drag hinge units, and the main rotor blade sleeves and spindles There are three hydraulic dampers which control the movements of the blades in the plane of rotation

Below the head is a unit comprising a rotating and fixed star, which transmits pitch control from three servo jacks, and imposes cyclic pitch variations on the blades

PRODUCTION PLANNING AND TOOLING

The methods adopted for producing any individual part are influenced by a number of variables, and local circumstances at particular Companies may lead them to use totally different methods for similar parts In view of this, I do not propose to give a detailed description of manufacturing techniques, except where I feel that these may be of general interest to those engaged in helicopter production

The jigging and tooling is the major item in the initial production expenditure, and has a considerable effect on the rate of production, and the cost of the product However small the number of helicopters, a certain amount of tooling is essential, as many of the components cannot be manufactured without it The remainer of the tooling expenditure is then largely dependent on the detail design, the quantity to be made, and the ingenuity of the jig and tool designer, and cannot be finally ascertained until the drawings have been planned in detail It is necessary, however, to have a target, and we have found that the following formula gives reasonably satisfactory results

$$T = C + \frac{N}{15}$$

where T = tooling cost in £'s
C = 75 × estimated man-hours for first production helicopter
N = total estimated man-hours for helicopters in batch

Our experience has been that the cost of tooling for helicopters is greater than the cost of tooling for fixed wing aircraft, owing to the larger number of forgings with a correspondingly high cost for dies, the larger number of special inspection gauges, and the necessity for more elaborate test and measuring equipment for the transmission items To illustrate this, the Dragonfly tooling cost for transmission was £100 per lb weight as against £65 per lb weight for the fabricated structure

To ensure that the sanctioned amount is spent to the best advantage, and to exercise the necessary control, the planning engineers must receive some guidance My experience of trying to work within tooling budgets has led me to suspect that certain basic principles, which may seem obvious, are apt to be lost sight of

At the inception of the Dragonfly, it was decided to tool for a quantity of thirty aircraft, and this necessarily meant a limited tooling budget Rather than make semi-permanent tooling for the majority of the details, we decided to keep within our budget by providing as many permanent production tools as possible, and very cheap temporary tooling for the remainder The section leader planners were given a target tooling figure for each component, and instructed to work on the following lines

They were to allocate jigs, tools and gauges wherever these were necessary for the sole purpose of guaranteeing interchangeability If a part could be manufactured free-hand or by very elementary tooling and still maintain interchangeability, production tools were not to be called for, unless it could be shown that the provision of such tooling would show a saving in manufacturing time equal in value to twice the cost of the tool The factor of two was selected, as it was felt that the amount of saving would always be over-estimated, and the cost of the tooling would be under-estimated If the proposed tooling met this test, then it was to be of such a nature as to produce a minimum quantity of two hundred aircraft sets before needing replacement

By these methods we avoided the situation whereby drawings issued at an early stage are tooled up to the maximum, with the result that before the tooling programme is complete, the budget has been spent, in which case the later components have to be made by free-hand methods or inadequately tooled As contracts for further Dragonflys were received, we progressively substituted permanent tooling for the elementary tools

When ordering materials for a batch of helicopters, bearing in mind the greater proportion of items which are suitable for production as forgings, stampings or extrusions, it is sound economics to order an excess quantity to justify the cost of the dies If this decision is not taken initially, it is unlikely that marginal cases will be reconsidered as further orders come along

A great deal of time can be saved in the tool design office, and in the tool room, by making the utmost use of the standardised details such as latch plates, jig pins, base plates, etc , which can be purchased from firms specialising in this class of work We have found that extensive use of these parts has resulted in a reduction in elapsed time, without any significant increase in the cost of the tools

MACHINE TOOL EQUIPMENT

The detail parts which comprise the transmission and rotor systems are comparatively large, and are made, in the main, from very high grade steels, and therefore call for heavier plant than that usually found in aircraft factories

In my view, copying lathes and copying millers are ideally suited for the heavy roughing involved, and can also be used for finishing work in a large number of cases, and I will now show two examples of production by means of copying machines, with comparisons of the time taken by more conventional methods The first item is a rotor blade end fitting (Fig 1), which is made from a stamping in S 65 steel, and was originally machined complete on horizontal and vertical milling machines This part is used on

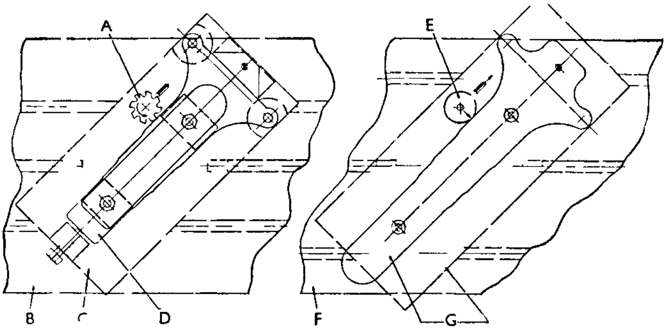

Fig 1 Profile Milling Machine

A—cutter , B—main table , C—jig , D—work piece ,
E—tracer , F—support table , G—profile template set up

Reproduced by kind permission of " The Aeroplane both Dragonfly and Whirlwind rotor blades, and we found great difficulty in meeting our production requirements

The operation lay-out was completely revised, and a 16″ × 30″ Hydro-Tel Miller was used for machining the whole of the outside profile, and the gap between the two tongues The work piece was set across the table at the angle shown, as the profile can be held to closer limits if the tracer pin does not travel parallel to the length of the machine table The steady application of the load facilities the use of tungsten carbide cutters without fear of excessive tooth chipping, and it will be noted that the semi-skilled operator is less likely to scrap expensive forgings by finishing below size

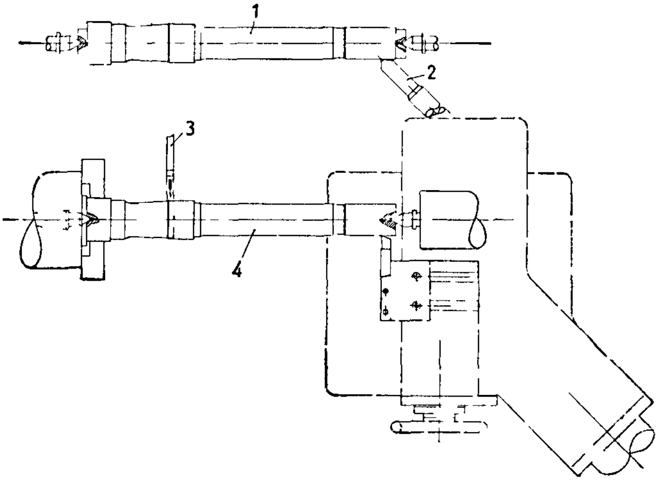

Fig 2 Profile Lathe

(1) Bar template, (2) Profile tracer, (3) Back tool set to fixed stops for machining return flange, (4) Work piece main shaft

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The machining time for these two operations is 4½ hours, the time taken previously on conventional millers being 7 hours

The next part is the main gear shaft used on the Whirlwind (Fig 2), which is rough machined on a Churchill-Redman copying lathe before heat treatment Here again, the continuous and steady cut facilitates the use of tungsten carbide tools, and the operation time on a Ward No 10 was reduced from 55 mins to 40 mins on the Churchill-Redman

These machines have four very great advantages for moderate sized batch production They can be operated by semi-skilled labour, and therefore can be double or treble shifted without too much difficulty, the percentage of spoilt work is trifling, the templates required are cheap and easily made, and the set-up time is negligible by comparison with conventional machines

PRODUCTION METHODS

In order to relieve our Machine Shop, and to reduce cost, we have made considerable use of fixed head routers, and spindling machines, for machining light alloys The essential feature of these machines is the high cutter speed

In addition, we are finding that a worthwhile time saving is obtained by developing special machining equipment A good example is the machining of the " D " section light alloy extrusion, which forms the leading edge of the rotor blade The machining of this spar, which is twenty-three feet long, would have presented many difficulties by normal methods, as apart from its length, it is twisted from one end to the other, and the wall thickness must be maintained within close limits The spar is drawn past a profile cutter by means of a cable attached to a powered winch, and spring loaded rollers on either side of the cutter hold the spar against rollers mounted on the fixture (Fig 3) The fixture forms a cross slide with vernier adjustment for regulating the depth of the cut As the remainder of the spar is not constrained in any way, the difficulties due to the twist do not arise In view of the close limit of the wall thickness previously referred to, it is necessary to take off the surplus metal in several cuts, in between each of which the thickness was originally checked from one end to the other by the use of a Sonizon machine (Fig 4), which measures the time required for a sound wave at the outer surface to be reflected back from the inner surface, the result being read off on an Oscillascope We have now developed a process by which the thickness of the wall can be measured during the profiling operation

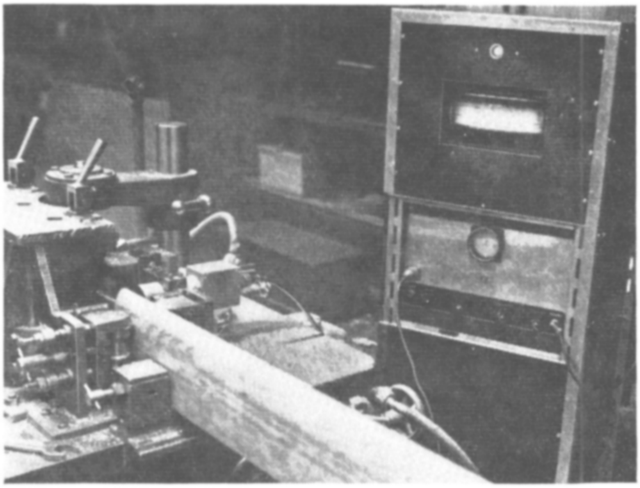

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Fig 3

A radio-active isotope is carried at the end of a bar inserted into one of the holes in the spar, the thickness at the measuring point being indicated by the dial on a modified Geiger Counter, which measures the flow of β rays through the metal, the rate being related to the thickness

Our initial machining efforts did not give a good enough finish, as the shape of the cutter prevented us from having as large a spiral angle as we would have wished, and the large tooth contact area, coupled with the fact that it was desirable to draw the spar past the cutter at high speed, gave a series of chatter marks from one end to the other This was later avoided by various small improvements, such as stiffening of the fixtures, redesign of the cutters, the fitment of a friction brake to steady the pull of the winch, and changes in the cutting lubricant

In order to get the desirable standard of surface finish, a polishing operation is carried out

The profile of the rotor blade is completed by a series of thin light alloy trailing edge sections, metal to metal cements being used in the manufacture of the section, and in their attachment to the spar

The large number of rotating parts and intricate mechanisms required by the transmission system, and the control devices on a helicopter, necessitate the manufacture of many parts to closer limits, and to higher standards of finish than normally would apply in the case of fixed-wing aircraft, and it took some time for the operators to adjust themselves to these higher standards

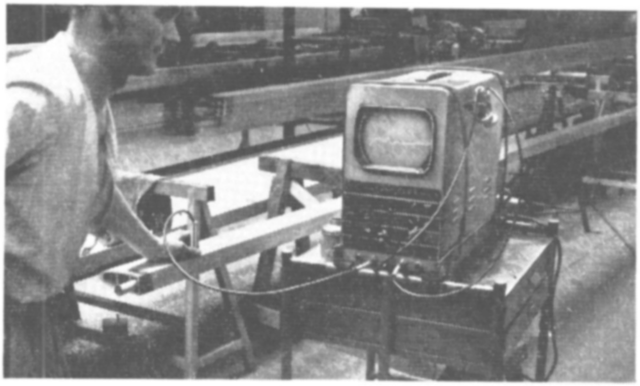

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Fig 4

An example of this is concerned with the fatigue failures experienced on the Dragonfly Main Rotor Hubs After two or three cases had been reported, it was decided to carry out a fatigue test simulating the conditions in actual service The period of testing was two thousand hours, and it was eventually established that the life of the hub could be considerably increased by grinding the surface of some washers, barrelling the outer diameter of the bearing housing very slightly, grinding the ends of the needle rollers in the bearing to a slightly different shape, and improving the standard of finish of the thread at the end of the hub arms The point of interest here is that the cost of the modifications themselves was trifling, as they were merely alterations to standards, but their effect on the quality of the product was very far reaching

Having been largely associated with production for seven years, those concerned with manufacture have acquired a full appreciation of the importance of quality engineering, and although difficulties in connection with standards of finish, limits, and special processes have not disappeared, they have receded to a point where they do not constitute a major problem

On the other hand, we have encountered little difficulty in the manufacture of fabricated items such as the fuselage and tail cone, as the close attention which has to be given to aerodynamic smoothness on high speed aeroplanes has not been necessary

The building jigs in use for the Whirlwind are relatively simple, and consist merely of structures on which pre-fabricated sub-assemblies, such as frames and longitudinal stringers, are mounted by pinning through tooling holes into locating brackets ready for skinning

No lecture on production is complete without a picture of an assembly line, and Fig 5 shows the intermediate stages up to final assembly of Whirlwind Helicopters now in the course of construction There are thirteen stations in the line, and each station is based on a cycle time of three working days An interesting point is, that included in the thirteen aircraft on the line when the photograph was taken, were three different types of military aircraft, and two different civil versions for various customers It will be appreciated that the diversity of equipment to be fitted in each of these different types practically defeated the normal production control and planning arrangements, and we arrived at a stage where the charge-hands supervising production had to draw from Stores the parts required to complete the individual assembly kits This meant that some of the parts were demanded at the last minute, instead of being supplied to the operators in advance, and production was unable to flow smoothly A partial solution to this difficulty was arrived at by the preparation of an omnibus group card, which consisted of a kit schedule for each operation, with crosses in each of a series of columns denoting the parts required for each particular variant of the main type

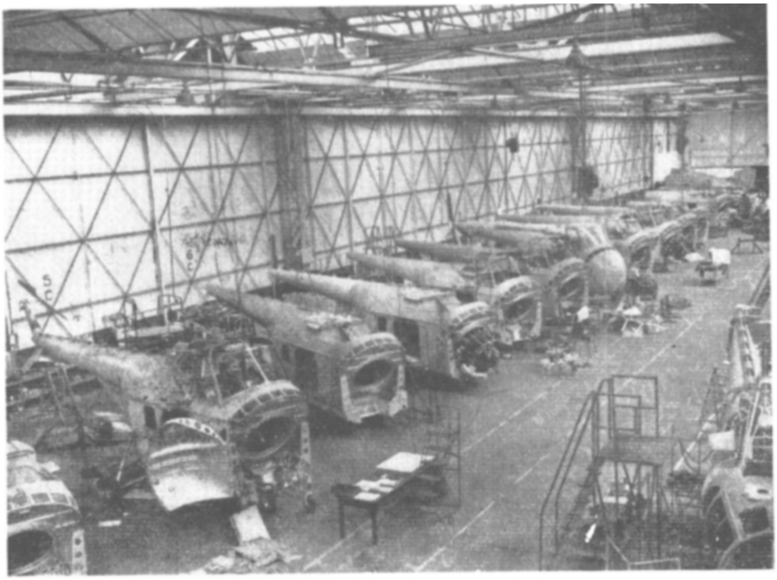

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Fig 5

TEST EQUIPMENT

The large number of rotating mechanisms, hydraulic jacks, dampers, etc, necessitate the provision of testing equipment on a very large scale Such units could be tested on the aircraft, but the delays in production involved are such as to be entirely uneconomic, and equipment should therefore be provided for bench testing wherever possible On Whirlwind production for example, we have a rotor blade matching and tracking machine, and every blade is matched and tracked against two master blades, so that the characteristics of each individual blade are identical It is therefore possible to supply single spare blades from stock, and avoid all the difficulties and inconveniences to operators and manufacturers which arise from having to supply blades in matched sets

We have rig tested every gear box we have built, and Fig 6 shows a diagrammatic arrangement of the rig now in use for Whirlwind production The rig consists essentially of the common arrangement of two standard helicopter gear boxes, the one on the left forming a permanent part of the rig, and the one on the right being the gear box under test The two output shafts are coupled together through the gear box at the top of the diagram, and the input shafts are coupled together at the lower end, the gear box at this point being connected to a 170 h p motor, the whole forming a closed circuit The motor is of the variable speed type, and can therefore be used to run the boxes at any desired rate of revolutions, and by means of the worm wheel shown in the lower right hand corner, the outer annulus gear is rotated, and this applies a load to all the gear teeth in the closed system, a gauge recording the pressure in the oil filled cylinder below the worm shaft

A considerable amount of equipment has been omitted from the diagram for simplicity, and the rig in fact incorporates oil coolers, oil temperature and pressure gauges, and trolleys to facilitate rapid loading and unloading of the gear box under test

The gear box rig was manufactured with the prime object of carrying out a standard running-in and acceptance test on production gear boxes, but we found it of great service during the hundred hour type test of the first Whirlwind

At a late stage in the test, suspicious noises from the main gear box led to a rapid shut down, and swarf adhering to the magnetic drain plug indicated serious damage to the gearing, which was confirmed when the assembly was stripped for examination

Further investigation established that the breakdown was caused by failure of the main input bevel gear, which had almost fractured in the region of the teeth, the cause being fatigue cracks initiated by the small root radius, and extended by an unfavourable direction of grain flow in the forging

A batch of hand forgings was hurriedly made, and having satisfied ourselves that the pattern of grain flow was now satisfactory, a new gear was cut with a larger fillet at the root, and a modified gear tooth shape It was decided to subject the new gear to a fatigue test of seventy-five hours duration, and we were able to do this much more quickly and conveniently on the test rig than would have been the case on the aircraft under test

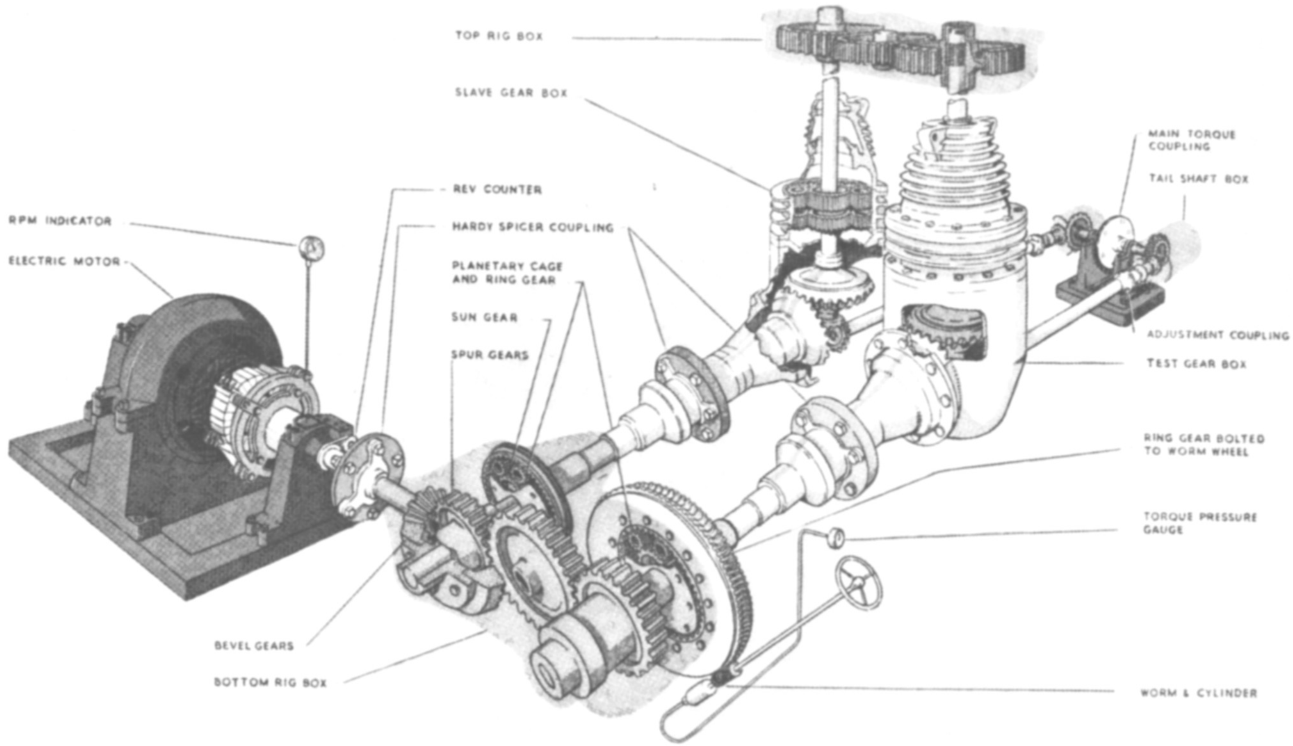

Fig 6 S55 Transmission main gear box test rig

ROTOR HEAD

The rotor head comprises a large number of detail parts which require precise machining to high standards of finish, but they are not fundamentally different from the machined items used in the many branches of the engineering industry, and the methods of manufacture are well established and widely known This does not imply, however, that the manufacture of the rotor head assembly is a simple business, as the large number of parts, and the multiplicity of machining operations is a problem in itself

In addition, careful adjustments on assembly are required to avoid any frictional or other unbalance in the hinge assemblies and the dampers

The dampers, which control blade " hunting," are of the simple dashpot type, with spring loaded ball valves in the piston, and a transfer part in the cylinder, which is regulated by an adjustable needle valve

The ball valves were subjected to a flow test before assembly into the piston, and the completed damper time-checked at a standard load, the rate of extension and closure being regulated by adjustments to the needle valve setting

In spite of these precautions, unsatisfactory results were obtained on flight tests, and after a long investigation, it transpired that ball valves which met the flow requirements at the test pressure might have different characteristics at other pressures, due to small variations in the shape of the approach to the orifice

The difficulty was overcome by machining the ball valve housings to closer limits, and checking the flow rates over a suitably wide range of pressures

The drag and flapping hinges both rotate on needle roller bearings, and if the needle races and the needles themselves are within the close tolerances called for on the drawings, there is no likelihood of any significant variation in the frictional resistance

The thrust bearing at the drag hinge and the Timken bearings on the rotor blade spindle, being preloaded, present more of an assembly problem

The collars which apply the pre-load are screwed down with torque-recording spanners, but the force actually transmitted to the bearing may vary considerably as a result of friction in the threads or at the face of the collars, and a high standard of finish at these points is essential

As a final precaution, the frictional torque of each hinge is checked with a spring balance

CONCLUSION

There are indications that the demand for civil helicopters may increase considerably in the next few years, and if this is so, there will be keen competition to capture a larger share of the market by reducing prices

On the assumption that the production staffs of the various Companies are fully aware of the importance of economical production, further increases in manufacturing efficiency can lead to marginal reductions only The heavy expenditure on design, development, tooling, special equipment, and servicing, has to be recovered against sales, and therefore the quantity to be

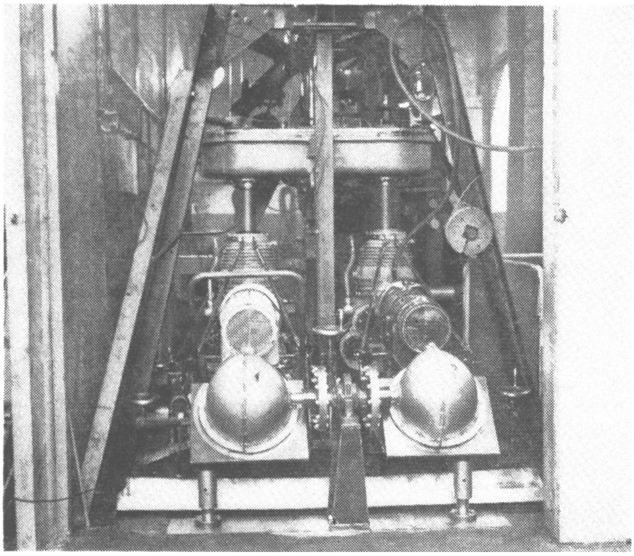

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Fig 7 Whirlwind main gear box test rig

produced is the most important factor in determining costs

It is, of course, possible to design a helicopter, or any other product, with low cost production as the main arbiter of design, but I believe this is a mistaken policy, as the customer is not interested in simplicity of manufacture but in simplicity of operation, and unfortunately the two rarely go hand in hand The progressively complicated manufacture of motor cars, which has been allied to a progressive reduction in price, is a perfect example of what I mean It would appear therefore that the only sound policy is to offer the customer a helicopter which will perform the services he requires, at the lowest possible price

My remarks that increases in manufacturing efficiency can only be marginal should not be taken to imply that they are therefore unimportant, and the production engineer must continue to seek low cost aids to production, and better utilisation of the equipment already in existence, so that more and better helicopters can be produced at lower cost

Similarly, the designer, whilst making his main objective the satisfaction of the customer, should keep himself fully acquainted with the latest methods of manufacture, so that he may be in a position to assess the relative production merits of various design possibilities

I have to thank Westland Aircraft Limited for permission to use the material included in this lecture, and to acknowledge the assistance of my colleagues in the Company for their co-operation in the preparation of illustrations, and in the collection of information

I am conscious of the fact that I have dealt with a very large subject in a rather incomplete manner, but I hope that what I have said will stimulate an interesting discussion which will fill in some of the gaps