The Simulation of Helicopter Flight Loads in Ground Tests

By

M J BRENNAN, B SC,

A M I MECH E, A F R AE S

You are all aware of the problems associated with the title of this lecture and, in order to avoid overlapping with Mr Hafner, I shall limit my part to the work that has been carried out on the Skeeter

In many respects the helicopter resembles an aircraft engine unit, and it therefore suggests itself that the routine method of testing engines should be applied to the helicopter Indeed at the beginning of 1951, a draft proposal to this effect was put forward, and is as follows

(1) The aircraft should be tested for functioning on the ground followed by the strain gauging of its transmission, control and rotor systems During the strain gauging a complete range of flight control should be covered

(2) Records made of these tests should be examined for any undue stress levels and stress oscillations

(3) Assuming compliance at this stage, the aircraft should be run for 50 hours on the ground and then stripped and examined intensively for fatigue and wear, using the standard engine practice

(4) Assuming this test is passed satisfactorily, a second identical prototype should be allowed into the air for brief handling trials followed by a repeat survey of strain gauge records in the air

(5) These records should then be examined and compared with those obtained during the ground tests

If it was found that the flight records differed considerably from those obtained on the ground, further ground tests should be carried out during which periodic stick movements and/or the erection of barriers beneath the rotors were to be introduced, in order to reproduce artificially the same stress levels and fluctuations as were obtained in the air

(6) Assuming that this could be achieved, it was intended that the complete helicopter should be subjected to an extensive fatigue run on the ground of some 360 hours, during which time the air loads and fluctuations would be simulated

A programme very similar to that described above has been completed, or is in the course of completion on the Skeeter

Before proceeding to describe the actual tests, details of the equipment will be discussed

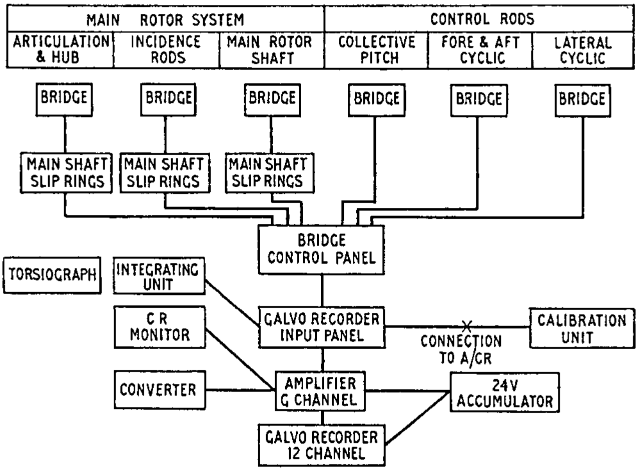
The Skeeter is the smallest British helicopter and is one of the lightest helicopters in the world Due to this fact, it has been at some disadvantage in as much as the general strain gauging equipment was of a heavy and bulky nature The equipment used to measure the loads consisted of complete strain gauge bridges, feeding signals through slip rings to a galvanometer for visual readings of steady strains, and to a galvanometer recording unit for fluctuating strains A block diagram of the equipment is shown in Fig 1

The galvanometer recording equipment, which was of the standard de Havilland vibration type, consisted of an input panel mounted near the roof of the cockpit, which received the signals from up to six separate circuits and contained the main press button for operating the recording camera and attenuator switches for adjusting the amplitude of the signal on the recording for each of the six channels separately The signal was then passed to a bank of six separate amplifiers mounted in a unit between the observer's legs This unit also contained the common time base control for the six monitor cathode ray tubes The amplified signal was sent both to the monitor unit mounted in front of the observer above the galvanometer panel and to the 12 channel galvanometer recorder which was mounted behind the engine The monitor unit contained six cathode ray tubes which indicated the amplitude of the record to the observer who could then adjust it with the attenuator switches This unit also contained the main switch for the D H equipment and a paper footage indicator, which was moved in pulses when the paper was actually moving in the recorder The recorder contained a battery of 12 galvanometer units, each reflecting a trace on sensitised paper The paper ran in a casette which was detachable for loading A timing signal of 52 5 pulses per second was incorporated in the recorder

Fig 1

Block diagram of the Strain Guage Recorder System Skeeter W F 112

(By kind permission of Flight)



The D H equipment, installed in the machine, was completed by a rotary converter, again mounted behind the engine which took current from the aircraft battery and supplied the remainder of the equipment, except the camera which had a separate supply from the same source A separate calibrator unit was supplied with the equipment and provided a high frequency alternating signal of adjustable amplitude A mark on a millivoltmeter indicated a standard calibration signal that was fed into all six channels at once This unit could be plugged into the input panel when required but was operated outside the machine

In order to reduce the weight of the equipment to a minimum all services were taken from one battery, including radio and aircraft instruments This imposed a heavy load on the battery of approximately 22 amps when the recording camera was working Since it was inadvisable to operate the recording gear from a battery which was at the same time in circuit with a generator, the aircraft generator was removed and the battery re-charged after every flight

The bridge control panel, mounted directly in front of the observer, contained the B P L 12 5—0—12 5 microamp dial galvanometer , a milliameter to measure the currents feeding the strain gauge bridges, dry batteries to supply the gauge circuits and potentiometers for balancing the bridges A rotary switch selected any one of the six channels and connected the galvanometer to the required bridge A sensitivity switch added a series resistance to the galvanometer , position 6 on this switch indicated no resistance and position 1 maximum resistance The " off " positions of this switch shorted the galvanometer A series of " on-off " switches, one for each channel, switched the bridge current milliameter into the selected circuit at the same time ensuring that the galvanometer was short circuited to prevent the large out of balance current from disturbing it

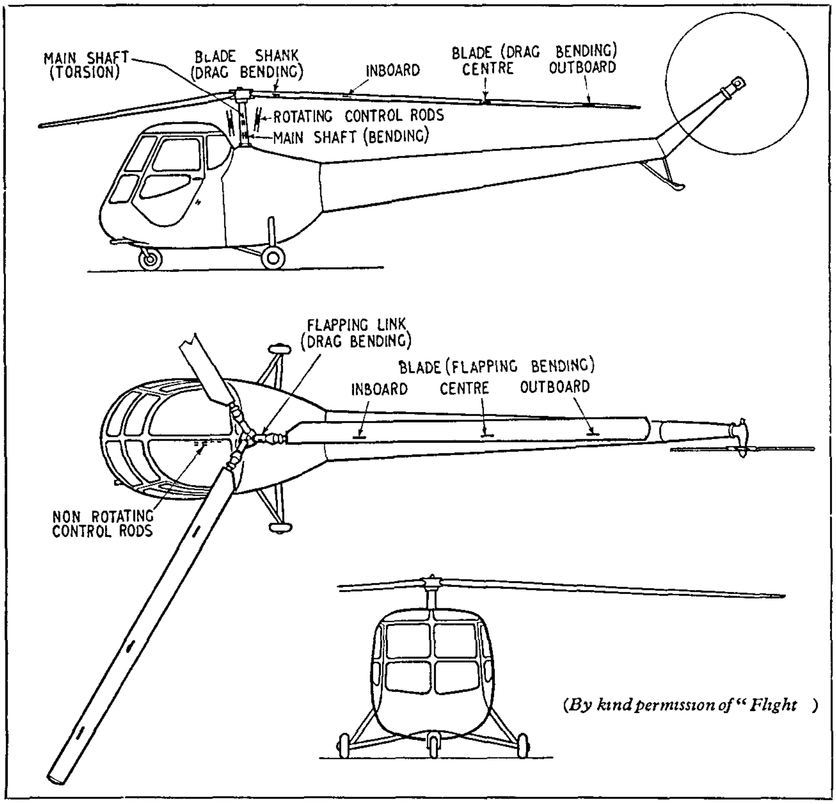


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Fig 2 Position of Strain Guage Bridges Skeeter W F 112

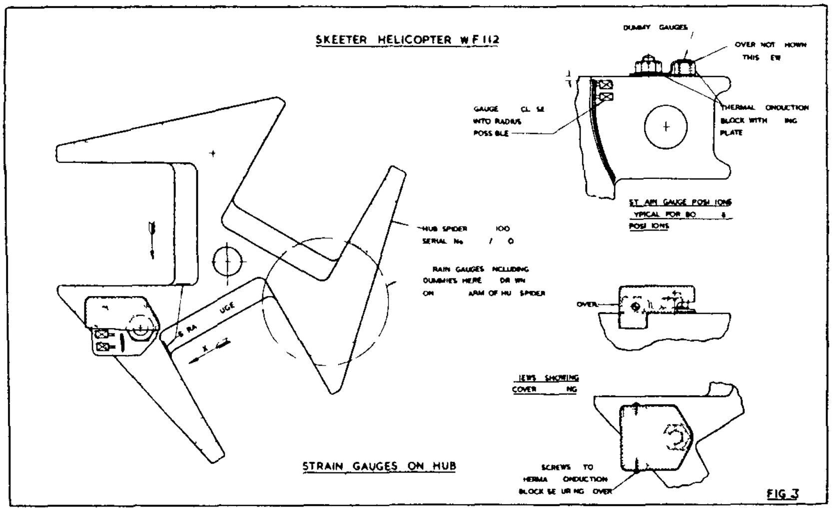

Fig 3 Strain Guages on Hub Skeeter W F 112

A Sperry-M I T torsiograph was fitted to the crankshaft extension of the clutch assembly and its signal fed into the D H equipment through a simple intergrating circuit Due to the relative movement of the engine and the surrounding structure, a suitable method of carrying the lead from the instrument was not found, and only a few recordings have been made with this instrument

The flight conditions were measured by the normal flight instruments with the addition of a direct reading damped accelerometer to the main instrument panel A fore and aft level was fitted to the instrumentation console, together with a nominal pitch level position indicator

The strain gauge positions are shown in Fig 2, and, as can be seen, the blade spars were strain gauged to measure flapping and drag plane bending moments on three positions along the blade Gauges can also be seen on the transmission which show the hub bridges and were so placed as to enable the actual strains to be measured at the most critical points on the hub forging These points had been previously determined from a brittle lacquer test carried out at R A E Fig 3 shows the positions of the gauges on the hub These were calibrated by applying the bending moment of the lug and calculating the stress applied at the gauges In this case two active gauges were attached to the stress bearing material and two dummy gauges were carried on brackets attached to the top of the hub, employing suitable thermal insulation

The articulation bridges were positioned to measure drag plane bending on the flapping link close to the flapping hinge Bridges were mounted on each of the three flapping links and at the shank of each blade, the shank bridges being considered as part of the articulation One bridge only in each position was used for the actual measurement, it being assumed that the three blades would behave in an identical manner

Two sets of bridges were provided on the main shaft, one to measure torsion and the other bending It was shown, by hanging the machine from the hub and turning the rotor that the bending bridge was not sensitive to tension and hence the results could only be accepted as pure bending moments

The loads in the control system were measured as direct loads in six of the rods, *i e*, the three rotating rods connecting the blade pitch change arms to the swashplate the one non-rotating rod in each of three main circuits (collective pitch, fore and aft cyclic pitch and lateral cyclic pitch) These bridges consisted of two gauges fixed to the rod and two dummies fixed to small plates carried in the same protective covering as the active gauges

TEST PROGRAMME

The number of slip rings limited the number of strain gauge bridges that could be used at any time to three on the rotating system The complete series of flight and ground tests were repeated for five sets of connections Samples of the readings of these tests can be seen from Fig 4 Fluctuating stress records only, were taken during take-off and running These series of tests were not always accomplished in one flight, usually two or even three flights being required

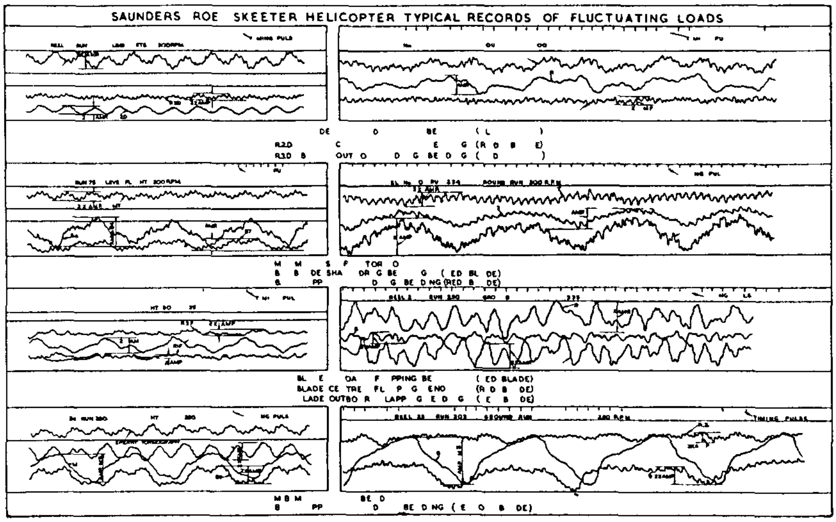

Fig 4 Typical Records of fluctuating loads Skeeter

GROUND TESTS

The ground test conditions were chosen after a few series of flight tests had been completed, to reproduce as far as possible the engine conditions used in flight The control column was held substantially central for all ground runs

As previously stated, the flight conditions were nominal and were held by the pilot to within approximately ±5 r p m in rotor speed and ±5 knots indicated in forward flight I should emphasise that no time was allowed for conditions to settle but, as the results do not appear to be sensitive to small changes in conditions this was no disadvantage

The weather during the tests varied from hot still air conditions to 15 knot gusty winds, no attempt being made to await similar weather conditions to complete the tests It was considered that these tests provided a good sample of average flight conditions

FLIGHT TEST

So much for the equipment and how it was carried, now we come to the method of testing Owing to the weight of the equipment, the time for each flight had to be reduced to the minimum, consequently the records were taken in the quickest possible way This was also desirable in cases where the flight conditions were at the limit of steady flight and the control positions were difficult for the pilot to maintain

Since space limitations in the cabin prevented the flight observer from writing down the results, these were transmitted over the aircraft radio to an observer on the ground The ground station was equipped with a " sound mirror " tape recorder and hence any doubtful readings could be subsequently checked by the flight observer

As the tests proceeded it was noted that the readings did not change significantly with small changes in flight conditions and it was unnecessary for the observer to read these conditions out to the ground observer The pilot flew the machine near to the nominal conditions and the observer concentrated in obtaining satisfactory amplitudes for the fluctuating signals and transmitting the mean readings of the galvanometer

RESULTS

A total of 311 recordings were made, including calibrations The numerical reduction of the galvanometer readings to load levels have been carried out in all cases except where a zero drift of the same order, or larger than, the signal deflection was found In most of these cases a valid reason for repeating these readings was found and there was no reason to doubt the final results

The fluctuating loads quoted are mean amplitudes, *i e*, one half the peak to peak amplitudes irrespective of frequency combinations as measured on the records , the principle being to choose a section of the record having the highest amplitudes, but to ignore any peaks not occuring cyclicly

The qualitative examination of the fluctuating results has only been carried out briefly but some trends have been established and are as follows

The first rotor order occurs in most of the records in varying degree On the main shaft in bending it was the main signal, whereas in torsion it was generally of low amplitude of less than that due to the 3rd order The first order amplitude was sometimes large in the articulations and on the blades in flapping, but in the drag plane it was small on the blades compared to the 3rd order amplitude As a general rule in cases where the first rotor was predominant it was roughly the same on the ground as in flight

A 3rd rotor order frequency occurred in the transmission and articulations in flight throughout the steady flight range This frequency, however, was only present during ground running when high power and revs were used A 3rd order frequency was present on the blades in drag, during ground runs as well as in flight, the amplitudes being in the main greater in flight

Engine vibrations, in particular second engine order (*i e* , once per firing stroke) and fourth engine order were transmitted through the transmission and into the blades in the drag plane It was noticeable that the drag dampers did not appreciably reduce the amplitude In most cases, engine amplitude was somewhat greater on the ground than in the air for similar engine conditions

Several of the records of blade flapping during ground running revealed a frequency of approximately 1600 c p m at 335 rotor r p m nominal, which appeared to be the fifth rotor order It was not noticeable in flight but increased with speed and boost during ground runs A similar frequency was just noticeable in the ground main shaft bending record at maximum speed and boost, but was again absent in flight

The accuracy of the results obtained was considered to be reasonable and, in general, it was thought that the maximum error was less than 5 per cent in the accepted results Any cases of large errors due to poor temperature compensation were corrected during calibration, but the exposed nature of the rotor and the air flow in flight may have affected the results to a small degree

It was concluded that the tests were sufficiently complete to show the level of both steady and fluctuating loads occuring on the rotor and transmission of the machine both in flight and during ground running However, it appeared that in the case of the blades, a more extensive programme of research was required to explain all the qualitative and quantitative results obtained, but the transmission behaved in a repeatable fashion and the results were consistent The control rod loads were small in all cases

Before continuing on the description of endurance ground runs, which have done more to indicate the small number of fatigue failures and wear, I would like to say that the method of testing which I have described and which split the loads into mean and fluctuating loads with distinct methods of recording, ensured greater accuracy than the more usual way of recording these two quantities together It was our opinion that such a method might well close other differences between ground and flight

Comparing the maximum loads measured, regardless of conditions of flight or ground running, we find that for most components strain gauged, the maximum steady load in flight was greater than the maximum steady load on the ground However, in the case of the fluctuating load, the maximum ground loads were greater than the flight loads in nearly all the components

I should emphasise that the engine vibrations, which are of a high frequency and without a doubt the start of fatigue failure are larger on the ground than in the air

One interesting result of the flight test was the discovery that the flapping angle in all conditions of flight, when the machine was loaded with the centre of gravity 4 7″ forward of the shaft, was only approximately 2½°

Since the flapping angle required during ground runs, to balance the tail rotor torque was of the same order, it was not surprising that no control movements were necessary to equal the level of loads, from this cause, found in flight

The preliminary stress clearance for fatigue has been obtained for most items of the transmission and blades by combining the most unfavourable steady and fluctuating loads met with in any condition of flight

From the foregoing results, it will be seen in practically all cases that the ground tests cover the flight cases for oscillating stresses, although the levels of stresses in the case of flight were higher However, it was our contention that, as the oscillating stresses are the predominating factor in the fatigue running, then, for the Skeeter at least, the ground running covers the flight envelope

ENDURANCE RUNNING WITH REFERENCE TO FATIGUE AND WEAR

Therefore endurance running has continued, from the inception of this aircraft, and over 200 hours have so far been accumulated to date During the whole of this time the tests have so far failed to produce evidence of defects of a serious nature In fact defects which did occur were of such a nature that they did not interfere with the normal course of endurance running and were accumulated during strip inspection periods

To facilitate detailed inspection, each component was broken down into its own assembly stage or details if requested The inspection consisted of a visual and high magnification examination—as stripped and after cleaning Intensified inspection by the use of Metro-Vickers Magnaflux Crack Detection unit, and a Whitening Methylated Spirit on aluminium alloy parts was carried out

The use of Bi-focal twin ranged Microscopes has helped to eliminate confusion and doubt on the parts where Metro-Vickers Magnaflux gave an abridged filed effect on radii under normal crack detection On aluminium alloy parts, however, while every precaution has been exercised in crack detection, vital examination has been omitted due to inaccessibility, *i e*, the internals of the main vertical shaft, intermediate shaft, tail shafts and other small bore shafts and pins

I should like now to discuss the condition of the component parts following an inspection check after 150 hours endurance running on the ground

The power unit installation has functioned satisfactorily throughout requiring only normal servicing In fact in this particular case, the engine had not been removed from the airframe for over 130 hours

The primary gear box has so far shown no signs of wear, the free-wheel having been over-run and then re-engaged on over 2,000 occasions without once missing The clutch fitted to the Skeeter has not given the slightest indication of trouble since it was introduced and has completed over 200 hours of running involving something in the order of about 3,000 engagements in which 500 were engaging the rotor at rest and the remainder when slip testing the free-wheel unit One item which has shown some signs of wear is the intermediate drive shaft, its life being estimated at approximately 75 hours and this is mainly connected with the needle bearing of assemblies An improved type of joint will be incorporated in future aircraft Although the secondary gear box is functioning satisfactorily inspection strips after 25 hour periods showed that the rotor brake drum backplate was unsatisfactory because of cracking around the attachment bolt holes It appeared at the time that the inertia of the steel brake drum was the main contributory factor affecting the failures on account of the presence of T V in the tail drive shaft However, since then, the moment of inertia of the drum has been reduced by one half, and this step appears to have eliminated the trouble

The remaining gear boxes, *i e*, the tail and angle gear boxes have functioned, like the primary gear boxes, perfectly The main rotor hub has, in the main, proved to be satisfactory although the hub centre has caused a considerable amount of concern regarding its stress analysis but it has been subjected to much more severe treatment during the ground running than would normally be the case in flight In the first place the continuous lift was in excess of that of normal flight on account of ground effect and secondly the flapping was more than normal on account of the 4° (built in) lateral cyclic tilt for hovering which was normally reduced in forward speed and also as a result of the peculiar characteristic inherent in the rotor blades, which were at that time being tested, in as much as there was a backward cyclic tilt of approximately 4½° which made a total of 6° cyclic control applied continuously during the endurance ground running The first 104 hours running was carried out with continuously applied flapping in the rotor system of the order of 4°, the remaining hours, to date, being carried out with flapping of the order of 6°

Apart from a failure of the rigid trailing edge, on an early set of blades, there is little to warrant mention here of our rotor blade development Although whilst flying through a severe hailstorm at Farnborough during the last S B A C Show, leading edges of the blades, were severly dented However, the early blades, as mentioned before, have acquired some 200 odd hours during the extensive programme of endurance running, with no signs of failure

Going on now to the tail rotor hub and tail rotor blades, very little wear has been experienced on the hub after some 200 hours, although the tail rotor gearbox mounting flange was subjected to a fatigue failure at that time, which is clearly shown in Fig 5 Again one blade of the tail rotor, was found to have a small crack on the trailing edge skin which started from immediately under the outermost rivet on the root end, extending for about ¼ in in the chordwise sense It was decided, at the time, to continue running with the blade in this condition for a further 25 hours in order to observe the progress if any of the crack, but no further appreciable lengthening of the crack was found and the skins on the blades were replaced, following 150 hours running, employing " snap " type rivet heads in place of the " countersunk " type originally used At the same time a fatigue failure of the port short exhaust pipe occurred and can be seen from the next slide, Fig 6

During this period the airframe was partly dismantled for visual examination and the pylon carefully examined for cracks, no apparent defects showing During the last 46 hours running of the 150 hour endurance ground run, the

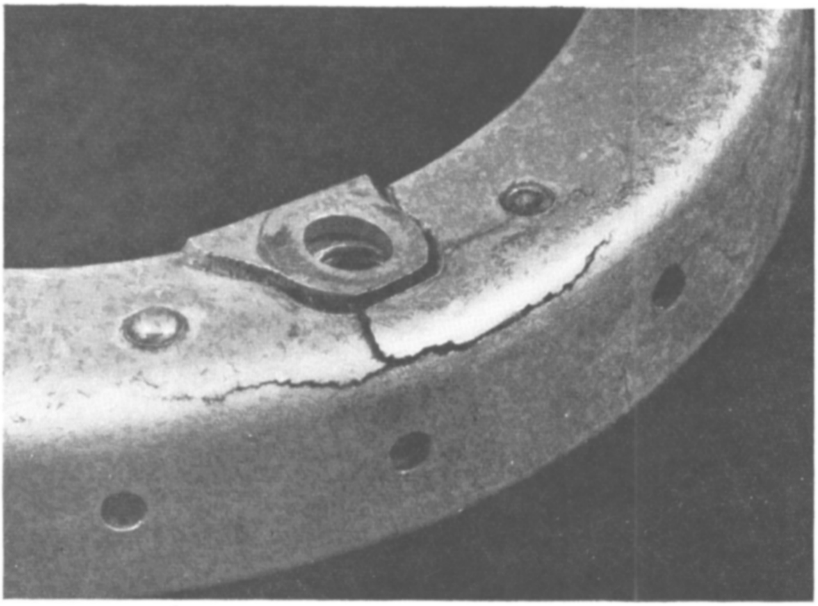

Fig. 5.

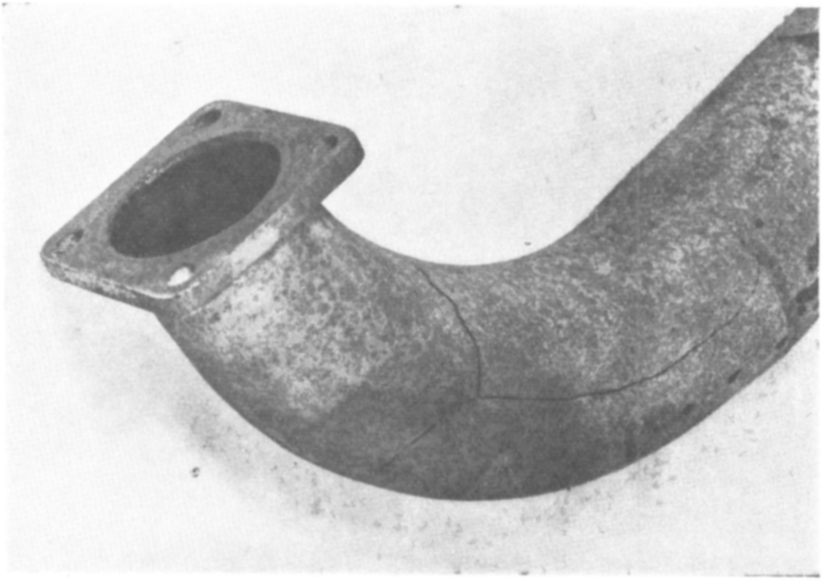

Fig. 6.

main rotor control system was subjected to an " into " pitch blade pitching moment amounting to approximately 20 lb at the end of the collective pitch lever although for normal operational use, the blades are so tuned that the forces are neutral

From what I have said and before I conclude, it will only be too apparent that the present instrumentation techniques are inappropriate and difficult in application to helicopters, and it was decided to develop rotor head mounted recording equipment for future use This equipment should be ready in the very near future and will enable substantial economies to be realised

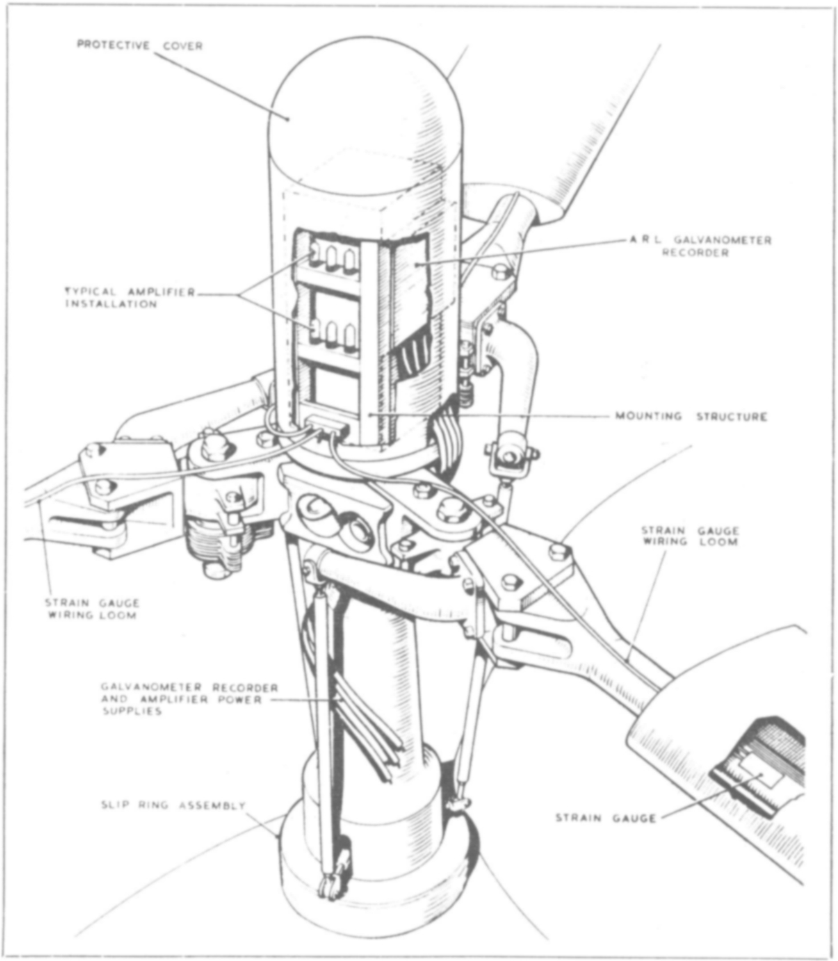

Fig 7 Rotor Head Mounted Recording Equipment

The rotor head mounted recording equipment, which will eliminate the necessity of slip rings is shown in Fig 7

I need not stress the importance of eliminating slip-rings in low-level signal circuits to you but I think I should say that although it is fairly easy to design efficient slip-rings, it is entirely another matter to maintain working efficiency in the field In fact they are one of the most prolific sources of trouble in practical tests, mainly because, in an endeavour to extract the maximum signal/noise ratio form the strain gauge slip-ring system, it is difficult to restrain a natural tendency to run the gauges at the maximum possible energising current This, of course, is heavily weighting the odds against gauge survival, and can also be a prolific source of drift in the case of steady stress measurements should these latter be absolutely essential

CONCLUSION

I should like to conclude this paper by stating that, at the commencement of the Skeeter development programme, it was our intention to carry out extensive strain gauge measurements in flight and on the ground, and to develop methods of simulating flight conditions on the ground by means of period stick movements or by barriers erected beneath the rotors The method finally adopted of measuring the stress levels and the stress oscillations separately, led to the conclusion that on the Skeeter design, the fatigue running on the ground could be considered to cover that in the air

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The Chairman I am sure that everyone found Mr Brennan's paper very interesting, and we are very obliged to him and to the Saunders-Roe Company for giving us an insight into the technical problems of measuring fluctuating stresses of such a complex mechanism as a helicopter rotor

The interesting point is that having accepted a given method of attack on the overall problem they have proceeded with an extensive series of tests to determine whether or not ground tests can cover all flight cases In the case of the Skeeter it appears from the results that this can be claimed If further tests—on other aircraft—substantiate the validity of this approach, then indeed a big step forward has been achieved

I will now move on to the second part of our programme tonight and call upon Mr Hafner, the Chief Designer of the Bristol Aeroplane Company to give us his talk on the same subject

It would be presumptuous of me to introduce Mr Hafner, because he is very much better known in the helicopter world than I am, but, to emphasize his very wide experience and knowledge of rotary wing aircraft may I remind you that the records show Mr Hafner has been engaged on fruitful helicopter development and research for no less than a quarter of a century This indeed is a notable achievement and is a measure of the extent of his contribution to the helicopter art