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A REVIEW OF RAE EXPERIMENTAL TECHNIQUES FOR ROTOR DYNAMICS AND AERODYNAMICS

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A REVIEW OF RAE EXPERIMENTAL TECHNIQUES FOR ROTOR DYNAMICS AND AERODYNAMICS

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SUMMARY

This paper describes the special in-flight experimental techniques which have been developed and used by the Royal Aircraft Establishment for flight research into the detailed aerodynamics, blade motion and structural loading of helicopter rotors.

Developments are traced from the use of a high speed camera, mounted on a semi-rigid rotor, for the measurement of blade motion generally, through to installations involving a number of heavily instrumented experimental blades and the employment of electronic data acquisition systems.

Rotor performance has been the subject of a number of research programmes and these have provided much useful data for the validation and extension of UK prediction methods. These experiments have been concerned primarily with the study of blade performance but also include temperature distribution measurements; the paper uses examples of these to illustrate the methods of blade instrumentation and the data acquisition and recording techniques. Special methods have been adopted for the calibration of the large numbers of sensors involved and these are outlined.

Rotor blade modification procedures are discussed with reference both to sensor installation and to the requirements of flight safety and airworthiness.

Improvements in analysis, processing methods, and computing equipment have proceeded in parallel with airborne system developments and the impact of the increased size and processing power of modern computers on the experimental procedures is considered.

1 INTRODUCTION

The techniques discussed in this paper have been developed by the Royal Aircraft Establishment (RAE) at Bedford in response to the demands of a long term programme of research into the aerodynamics of helicopter rotors. This research programme has the prime aim of validating and extending rotor prediction methods. In-flight research methods were chosen because of the difficulties encountered in the scaling of rotor models and other limitations of wind tunnel facilities.

Detailed measurements have been made in-flight of the aerodynamics of specific aerofoil sections and their relationship to the dynamic loading of rotor blades (Ref 1). It is particularly noteworthy that in each case a standard, in-service, machine (Wessex, Puma) has been employed with modification only to detailed parts, for example the blades, and the addition of suitable data recording and load monitoring equipment.

2 HISTORICAL BACKGROUND

In the early part of the last decade interest in the dynamics and aerodynamics of rotor blades at RAE Bedford centred on two areas of flight research. One of these was the determination of the mode shapes used to describe the deformation of the blades of a hingeless rotor research helicopter. These were obtained by means of a hub mounted high speed camera which filmed the blade in flight. The processed 16 mm film was subsequently analysed by hand with reference to the apparent position of the blade markings in the frame and the results transferred to computer. In spite of the use of semi-automatic film reading methods this procedure was, of course, extremely tedious and in consequence only a small number of flight test conditions could be analysed.

A second area of interest was the measurement of the drag of improved aerofoil sections. These measurements were required to verify aerofoil design work previously carried out in the wind tunnels of the RAE and the National Physical Laboratory. For this purpose special Balsa wood blade "Gloves" were manufactured to fit the ends of otherwise standard rotor blades. These gloves carried chordwise rows of pressure holes and, at the trailing edge, pitot rakes of miniature design. Measurement of the pressures at these points enabled the lift and drag of the aerofoil to be determined. Small bore piping linked the pitots and chordwise holes to the rotor hub via the centre of the blade 'D' spar and a Scanivalve and pressure sensor of high quality were used to scan the pitot pressure outputs. Data was recorded on photographic paper using a battery powered recorder mounted on the hub and controlled by a radio switch. Fig 2 shows this general arrangement when in use for the comparison of two aerofoil sections. (Ref 2).

Two important points are illustrated by this arrangement; firstly the data was not in a form in which automatic data processing could be used to reduce it and secondly the long, narrow, pipes introduced considerable time lags in the dynamic response of the measurement system. The latter limited the measurement of pressure distributions to the hover, where the pressures are substantially steady. These experiments were successful and allowed the Glove technique to be developed to a point where great confidence in the manufacturing and flight clearance of modified blade sections was obtained.

During these experiments it had been possible to carry out some flight assessment of several different varieties of miniature pressure sensor, of which the most successful was the silicon diaphragm, semiconductor strain gauge type. These had insignificant time lags in their dynamic response and thus could be used for measurements at all flight speeds. Several suitable sensors are now available from different manufacturers. Fig 3 illustrates sensors of the type most commonly in use at RAE.

A complete helicopter rotor research data system was then constructed with the following key features:

1 The introduction and development of the blade 'Glove' technique for the surface mounting of pressure sensors and the acceptance of the glove in relation to flight safety considerations.

2 The use of miniature semiconductor pressure sensors and appropriate rotor mounted signal conditioning electronics.

3 The provision of specialised airborne recording systems having sufficient capacity for the data rates involved.

4 The generation of suitable interactive data processing and display software to allow easy access to the results of the tests.

Over the past decade the system components have been subject to continual development to meet the increasing demands of flight trials. If data rate may be taken as an indicator of the capability of the experimental installation, then an increase from 10,000 samples/sec to 256,000 samples/sec over the period clearly shows how extensive the expansion has been.

3 BLADE INSTRUMENTATION TECHNIQUES

3.1 General

Main rotor blades of both Wessex and Puma helicopters have been instrumented with strain gauges and pressure sensors. To date only metal blades have been instrumented; there is a ready supply of these in the UK and their D spar construction lends itself to the installation of pressure sensors. Methods of installation for composite fibre blades and for wrapped steel blades are under consideration. Table 1 lists some of the modified blade schemes which have been employed.

TABLE 1 SOME BLADE SCHEMES

A Tip gloves, aerofoil drag comparison.

B Leading and trailing edge spanwise array, Fig 4.

C Chordwise array around an experimental aerofoil.

D Thermocouple array with independent blade mounted conditioning.

E Stain gauged array for study of blade aeroelasticity.

F RAE swept tip.

3.2 Strain gauge practice

In the case of blades instrumented only with strain gauges normal strain gauge practice is followed. After paint has been removed and the surface cleaned the gauges are bonded to the blade using a cement recommended by the gauge manufacturer. The gauges are invariably connected in the form of four arm

Wheatstone bridges having four terminals; these are usually terminated on a small panel near to the gauge measurement station which allows groups of gauges to be connected together and also allows the comparatively fine wire links to the gauges to be joined to a type of wire more suitable for signal routing along the blade.

3.3 Pressure sensors

In the case of blades instrumented with pressure sensors it is necessary to ensure that the sensor is flush with the blade surface, at least locally. If this is not so then, for aerofoil sections of the size and shape used for helicopters, the small but finite depth of these devices is sufficient to disturb the flow. The first way in which this is achieved is by removal of the blade surface to form a depression of sufficient depth as to accommodate the sensor. Great care is taken to ensure that the blade material is uniformly removed and the surface is left free from scratches or abrasions. This practice is aided at the leading edge of a blade where the additional depth of the polyeurythane anti-erosion strip may be pierced to allow flush mounting of the sensor. The depth available after this procedure has been carried out (of the order of 1.5 mm) is normally sufficient and is commensurate with the amount of surface modification allowed for in the standard schedule of repair to blades (for the removal of scratches and abrasions) during their normal lifetime. Greater depths, coupled with the installation of relatively large numbers of sensors, may impose penalties in relation to the fatigue characteristics of the blade spar and discussion with the aircraft design authority (Aerospatiale in the case of the Puma) becomes necessary. This can lead to costly fatigue testing of modified blade samples and it is therefore necessary to apply this installation method with care.

The alternative method of preserving the aerofoil section is, as has been indicated, the use of a Balsa wood glove. This allows an aerofoil shape to be built up to suit the test requirements and provides a workable surface into which the pressure sensors, strain gauges and their associated wiring may by set without modification of the blade structure. After the installation of the sensors has been completed and the wiring run through channels cut in the glove the surface is covered with an epoxy and fibreglass layer, about 0.2 m thick, which is smoothed to the final section and is used to protect the soft balsa from surface damage. The semiconductor sensor elements are isolated from blade deformation forces by encapsulation of the elements in rectangular housings and supporting them on silicon rubber compound.

One disadvantage in the balsa glove method is that the blades are not proof against damage in flight for example, due to precipitation, and great care has also to be exercised in the handling and transport of the blades after modification.

Some examples of test aerofoil gloves are shown in the illustrations. Fig 5 shows one of the swept tip gloves under construction, the wiring loom and routing to the sensors may clearly be seen.

Fig 6 shows a blade fitted with a special cambered aerofoil designed for operation at about 75% of the rotor radius. Additionally the operating region of blade incidence was greater than that of the basic blade and the test section was therefore inclined by means of trailing edge pocket modification. This was flown against a suitably balanced standard blade during the tests.

3.4 Blade balancing methods

It is of course necessary to provide for the in-flight balance of modified blades in relation to the centrifugal and the torsional forces. Each experimental blade is designed to have the same moment about the rotor axis as the blade which flies opposite to it. Final adjustments are made, using the normal balance weights provided for this purpose, by assembling the pairs of blades on a specially constructed static balance rig. The chordwise mass distribution is chosen to prevent undesirable twisting of the blades, as an example the swept tip blades carry an extra mass in the leading edge for this purpose.

3.5 Blade wiring methods

The electrical power to and the output from the sensors is carried from a distribution panel at the blade root by means of parallel enamelled copper wires. These wires are laid together on a jig and joined with an impact type adhesive to form a flat strip. After shaping, and allowance for the branches relating to each of the groups of sensors, the strip is joined to the blade surface after the latter has been stripped and cleaned. Once again an impact type of adhesive is used. The wire diameter chosen is a compromise between the need to provide a large number of wires in a limited space and ease of application and lay out. This results in the general use of wire of 0.28 mm diameter. A number of different wiring methods have been attempted over the years but the use of single copper wires has now become standard for all test blades.

In general the four wires to each of the sensor bridge terminals are carried direct to the blade root, however to reduce the overall number of wires on heavily instrumented blades, a single pair of wires may be used occasionally to carry the electrical power to a small group of individual strain gauge stations.

In the case of semiconductor pressure sensors this is not an acceptable procedure as these sensors have temperature compensation resistors in each power lead and the four wires are therefore taken direct to the blade root where the compensation resistors are located on suitable sub-panels. The wiring is normally laid along the 'D' spar in order to avoid joints between the blade 'pockets' since these have relative movement in flight and will cause wire breakage after a relatively short time. Consideration is also given to the provision of a proper venting path for the pressurised gas used in the Blade Inspection Method (BIM). After the loom is fixed to the blade the wires are coated in an epoxy to stabilise and protect the installation.

In general these looms are run along the underside of the blade at or near the line of the blade chordwise centre of gravity where they will have the least effect on the mass distribution and the airflow.

3.6 Installation for blade surface temperatures

One important exception to the procedures outlined above has been the instrumentation of a blade for the measurement of temperature distribution. In this installation a number of chordwise arrays of thermocouples were placed on the surface of a blade. Each array of thermocouples consisted of sets of pairs of fine (.05 mm) chromel/alumel wires welded at the thermo-junction and hot pressed between sheets of 0.1 mm polythene about 150 mm wide passed fully round the blade. The fine thermocouple wire outputs were welded to Ni-Al and Ni-Cr transmission wiring, used for mechanical strength and formed into a flat parallel loom, similar to the copper looms described above and attached to the blade in an identical manner. The loom was terminated, at the blade root, in an encapsulated multiplexer, amplifier and reference junction assembly designed to interface to the recording equipment in the cabin.

3.7 The use of hot wires and films

At one stage interest was shown in the use of hot wires, or more appropriately, hot films for the indication of rotor blade stall. This arose from the simple nature of the hot film which is essentially a film of platinum deposited upon a glass or quartz substrate and heated to a temperture well above ambient (150 deg K). The cooling effect of the air flow over the film gives rise to marked changes in the electrical resistance of the film in relation to the flow velocity, in particular the transition between laminar and turbulent flow may be easily observed, Ref 4. It was hoped that arrays formed of large numbers of these would allow phenomena such as stall boundaries to be mapped. In practice, however, difficulties arose in the production of uniform samples of the films which consisted of a 2 mm x 1 mm platinum strip about 1.0 micron thick deposited on to quartz discs 2 mm in diameter. Special feedback driving circuits were developed but, largely due to the heat dissipation requirements of these items, proved more cumbersome in practice than the equivalent pressure sensor conditioning. The need for extra rotor head wiring to cater for alternative circuit systems and the considerable electrical power requirements of the films and their drivers made their use in arrays of any useful size impractical and, although considerable success was obtained with individual films, this technique has not been persued further in helicopter research at RAE.

4 AIRBORNE RECORDING SYSTEMS

The airborne recording equipment may be considered in two parts. The first of these is the circuitry which is dedicated to the conditioning and processing of the sensor outputs; the second part is associated with the timing and control of the recording processes. Of these the first is generally independent of the recording method used while the second is designed to accept standardised signal levels and is closely associated with the recording hardware. Ref 3 outlines some of the details of an early airborne system.

4.1 Signal conditioning

The design philosophy used in the development of the signal conditioning parts of the RAE airborne installations has been based on the use of multichannel slip ring assemblies. These allow power to be supplied to the rotor and any potential errors due to slip ring electrical noise to be overcome by placing the signal conditioning amplifiers required by each sensor on the rotating part of the system. This also allows the number of rings to be reduced in any given installation since the amplifier outputs are single pole as opposed to the sensors which generally have multiple outputs and therefore require more connections per channel.

Some comment on the use of slip rings is perhaps appropriate. Firstly, the extreme simplicity of the ring principle results in an electrical element having an unlimited dynamic range and a wide signal frequency bandwidth. Secondly, they are not polarised and do not have significant offset or bias voltages. While rotating, however, there may be variation in the effective resistance of the ring and brush pair due to changes in the brush dynamic pressure or surface damage but this may be overcome if suitable circuit impedances are presented to it. A well designed ring assembly will give many hours of use while requiring little maintenance and that by relatively unskilled personnel.

These qualities allow the effects of the slip rings to be neglected in the general design of the conditioning system and all RAE instrumented rotors carry an amplifier assembly which converts the two-wire low-level sensor signals to standard range high level (usually ±5 volts) single wire signals referred to a common return.

Sensor excitation and electrical power for the conditioning circuitry was originally fed through the slip rings from stabilised sources in the cabin. However, with the increase in the installed numbers of sensors and the corresponding increase in their power requirements (100 watts for a current installation) it has become the practice to supply the entire rotor head assembly with raw aircraft 28 volts DC and convert to the required power levels after the rings using a number of small DC-DC converters. This practice avoids long power feeds and thus improves regulation and is more economical in the number of rings used.

In some cases insufficient rings are available, in such cases it is necessary to multiplex the signal outputs. This is done at the highest signal level (that is, after the amplifier output). This means that the anti-aliasing filters required by the multiplexer must also be included in the rotating system. Filters of the 4th order are normally used as a compromise between complexity and sharp cut-off in RAE rotor head assemblies. In addition to the anti-aliasing filters it has been found essential to include, at the input of each amplifier, a passive filter designed to remove interference signals from low frequency transmitters in the 10 KHz to 500 KHz band. The long blade wiring and relatively low level of sensor output signal makes the amplifier susceptible to this type of interference; typically, the filter is designed to have at least 30db of attenuation at 50 KHz.

Switching information is supplied to the rotor head via the rings using balanced logic drivers and receivers and these in turn provide addresses to the amplifier cards by means of a bus system.

The approach outlined above has generated rotor data conditioners which are self contained and may be tested and calibrated independently of the remainder of the airborne system with which they operate. Fig 7 shows the principles of operation of a 128 channel rotor head conditioning system; Fig 8 is a view of hardware after installation.

4.2 Control and timing

The original designs of recording and control equipment were based on the use of dedicated hardwired logical systems programmed automatically to record fixed length sequences initiated by the flight observer on reaching the required test condition. This arrangement gave rise to fixed recording formats and procedures. The final data recording process used analogue magnetic tape as a medium and required multiplexing of the limited number of tape tracks available. The methods employed for this all depended upon the use of one or more tape tracks to carry the multiplexer address information. The multiplexer timing and selection was related to the rotor azimuth as this was regarded as the most natural method of acquiring, analysing and displaying rotor data.

To simplify the transfer of the data to a computer compatible form whole numbers of rotor rotations were recorded and, since the nature of rotor data is cyclic and therefore repetitive by rotation, only comparatively short recordings were made; 2, 4, 8, 16 rotations being typical and 256 samples of each channel per rotation of the rotor eventually becoming the standard. The control systems were therefore designed to accept the signal from a rotor shaft azimuth pick off and to handle the starting, run-up and stopping of the tape in order to record predefined blocks of multiplexed rotor data. Included in each block were short periods of calibration signal which were used to reduce substantially the drift in the analogue processes. A quartz timing reference was also provided to allow tape speed changes to be corrected during the replay operation and to enable the rotor speed, and hence blade velocities, to be calculated during analysis.

The use of such a rigid recording format allowed the requirements of the ground computer (for example, file sizes) to be defined and, more importantly, allowed a variety of automatic data checks to be made at an early stage in the reduction procedure. Fig 9 sketches the principles of a typical analogue recording scheme.

Since the analogue FM technique required a dedicated recorder the nominally static aircraft trim and control parameters which define the flight test environment were recorded on a separate tape and later combined with the rotor data during the analysis.

The introduction of digital magnetic tape as the prime recording medium and the need to change the recording and control formats rapidly has led to the adoption of methods based on the use of a high speed minicomputer and a buffer or cache store. These methods allow the data to be acquired at a high rate, as required by the rotor dynamics, and then merged, at a much lower rate, with the aircraft trim and stress monitoring parameters.

The data rates encountered in the large systems currently in use lie in the order of 200,000 samples/sec; such rates are beyond the capabilites of the FM analogue recording equipment and are very much higher than those required in the recording of the basic aircraft parameters (typically numbering 64) for which total data rates of the order of 8,000 samples/sec may be adequate. In addition to the great flexibility afforded by such a processor based system it is also possible to use the processor to automate hardware checks and calibration procedures. Fig 10 sketches the principles of the typical digital recording scheme.

It has been found that trials are greatly facilitated if the test observer in the aircraft is provided with an oscilloscope display of current data; this is also generated by the on board computer and allows a variety of significant displays to be presented. The use of this display enables the servicability of large numbers of gauges and their associated circuitry to be constantly monitored and thus greatly increases confidence during the trials.

Table 2 illustrates some of the airborne computer sub-programs which have been provided as aids to the operation of an aircraft system.

TABLE 2 AIRBORNE PROGRAM SEGMENTS

1 Tests all buffer store locations and displays addresses and faulty bit patterns of all those, if any, found unserviceable.

2 Scans all rotor head channels and checks that these lie within preset limits; displays faulty channel addresses.

3 Displays the current decimal digital value of a selected rotor head channel.

4 Displays the current rotor speed value RPM as a check on system timing and correct rotor shaft sensing.

5 Generates standard voltage calibration steps for use in signal tracing and in strain gauge deflection.

6 Acquires data from rotor in accordance with the parameters set up in the software. (Number of rotations, etc)

5 FLIGHT SAFETY CONSIDERATIONS

Airworthiness and flight safety are of paramount importance in these as in any other flight trials.

It is clear that the most productive tests will be carried out at, or beyond, the limits of the normal aircraft flight envelope where changes to blade form are most effective and where the fluctuating mechanical loads are likely to be at their greatest; these loads are bound to result in high fatigue damage rates. However, high fatigue rates may be tolerated if the loads are carefully monitored and the damage taken into account in estimating the remaining life of components. The short duration of the recorded sequences enables key results to be obtained without operating the test aircraft in damaging conditions for lengthy periods. In addition the use of partially used but readily available metal blades, which may reasonably be scrapped after the completion of the tests, becomes cost effective.

In the case of the Puma the RAE have obtained special dispensations from the manufacturers of the aircraft (Aerospatiale) to fly modified blade sets provided certain formalities are observed in the conduct of the flight tests; these relate to the monitoring of the mechanical loads and their effect on the aircraft and its structure. In particular the real time monitoring of certain specified load parameters is made mandatory. As a matter of routine therefore, all flying of such blade sets is approached with caution. A period of ground running is followed by gentle hovering before manoeuvre into forward flight. During this phase a continous monitor is maintained both of the blade track and of vibration levels; this is carried out using standard tracking methods, in particular the Chadwick strobe lamp, and appropriate adjustments are made at each stage. These adjustments are usually aimed at the provision of satisfactory track over that region of the flight envelope in which most of the trials flying is to be carried out; this is then extended as far as possible across the aircraft flight envelope.

In addition to checks on the blade track the loads in critical parts of the aircraft structure are continously monitored by the aircrew using moving coil peak load indicators. In order to minimise the crew workload only the three most critical of these are displayed in the aircraft while the remainder are relayed to a safety pilot on the ground by means of a telemetry link. This member of the trials team can use a dedicated radio frequency to forewarn of any untoward increase in stress level during the trial and thus reduce the risks involved.

The continuous trace records provided by the telemetered output may be used to estimate the penalty, if any, incurred during the trial by cross-reference between the peak loads and fatigue damage tables or curves provided by the aircraft manufacturer. Until comparatively recently this task was performed by hand but, in order to conserve manpower, a small minicomputer has been installed to provide fatigue damage histories automatically. The critical loads are also recorded on the airborne magnetic tape in addition to the loads in components considered unlikely to warrant real time monitoring. From this information a complete knowledge of the airworthiness of the airframe, the control and transmission systems and of the blade set fitted to the aircraft is maintained.

6 ANALYSIS PROCEDURES AND SOFTWARE

Part of the general development of the helicopter rotor flight data system was in response to the need to provide suitable analysis software; in the absence of any suitable commercial product this was designed, written, and tested "in-house" by RAE personnel.

The first set of programs, which were intended for aerofoil comparison work and were known under the general heading of RPP also provided a control for the interface between the analogue tape replay systems and a Xerox Sigma 8 processor. The interface was accomplished via an Applied Dynamics AD4 analogue computer with analogue digital conversion submodules and formed part of a simulation facility.

Timing recovery, scaling of the analogue signals and tape speed (flutter) correction were all achieved by patch programming the AD4 amplifiers to form variable gain modules, monostable time delays, sample-hold circuits and even a phase-locked oscillator. The first processing program (RPP1) set up the interface and, using interrupt techniques, converted the data to digital words at 1/8 of the recorded flight speed. These were then transferred to computer tape. (Refs 3, 5). After transfer the RPP software checked the tape for areas of poor data and provided a print out to allow the general quality of the information to be assessed by the operator.

To enable the long term shifts in the pressure sensor zeros due to electrical drift and changes in ambient pressure to be eliminated special reference events were recorded on the airborne tape while the aircraft was on the ground with rotors stationary. Program RPP2 identified these events as calibrations and was able to take these shifts into account in the analysis; RPP2 also applied drift correction to each of the blocks of data representing an event in the trial. It remains the practice to record reference events such as these in spite of subsequent developments.

The main data analysis program (RPP3) then reduced the data to suitable aerodynamic coefficient form ready for an interactive display program (RPP4) and a cine film generation program (RPP5); chordwise curve fitting and integration routines were also provided to enable the calculation of coefficients of lift, drag and pitching moment to be carried out. As an illustration of the output of the data reduction processes a single frame, taken from one of the films generated by program RPP5, is shown in Fig 11. This program generated, from the reduced data, continuous anamated films which, on projection at normal speed, enabled the rapid cyclic fluctuations in chordwise pressure distribution to be clearly displayed.

The development of such a suite of software provided valuable experience in this field and facilitated the preparation of a second suite when the airborne formats were later updated to allow higher recording densities and changes in blade layout to be accommodated. The second suite of programs (PUMA 1 to PUMA 9) provided functions broadly similar to those of RPP but with an increased use of disc file processing rather than magnetic tape. A new set of display options suited to the altered blade layout and a relatively simple access to the uncalibrated data were also provided.

During the latter phase of software development it became apparent that there existed a need for a powerful general purpose software package to perform the reduction of helicopter data and which would provide the functions in a reasonably convenient manner. Under a cooperation program between the United Kingdom and the USA, helicopter data processing requirements have been combined and have led to the development, by Bell Helicopter - Textron, of a suite named DATAMAP: Data from Aeromechanics Test and Analytics - Management and Analysis Package, Ref 6. DATAMAP allows the generation of a wide variety of display formats and also contains useful features such as signal filtering and averaging and frequency analysis; DATAMAP is also suitable for other forms of unsteady aerofoil testing. One important feature of this package is the ability to merge data from flight tests with the calculated data from theoretical rotor models thus allowing the direct comparison of measurement and prediction.

Current software effort is being expended in the rationalisation of the processing interface between the digital tape replay system and DATAMAP in order to speed the analysis path and to automate the procedures as far as is conveniently possible.

7 CALIBRATION METHODS

The calibration of strain gauges is carried out by conventional means; loads are applied to instrumented sections and the electrical deflection at the output of the associated conditioning amplifier noted. Often the load applied is only a small fraction of the working load of the item to be calibrated, in such cases a sensitive instrument, such as a Digital Voltmeter, is used to measure the small calibration output changes. The scale factors thus determined are then used to generate equivalent signal voltages which may by injected into the system for the calibration of display or recording equipment. This approach assumes that the small signal calibration may confidently be extrapolated over a wide range since the items gauged are of high quality material operated well within the elastic limit.

Early installations of pressure sensors were calibrated by hand using a special rubber pad connected to a low pressure suction pump and reservoir. Apart from the obvious manual effort required in calibrating an increasingly large number of individual sensors it was only possible to apply negative calibration pressure differentials. There also existed some doubt as to the effect of the local mechanical force acting upon the blade over the sensor area and the possible introduction of errors due to distortion of the sensor casing.

These questions have led to the construction of a purpose built test and calibration chamber from a steel tube 10 metres in length and 1.5 metres in diameter and sealed at each end by thick plates. The tube and ends are of sufficient strength to allow a pressure differential of ±2 BAR to be obtained. The chamber is large enough to contain the largest modified blades anticipated and allows all sensors to be calibrated in one single sweep. Fig 12 shows the chamber in use beside the test aircraft to which it is connected by means of an umbilical cable. The reference pressure in the chamber is monitored by means of a mercury manometer and a table of sensor outputs may be obtained at each calibration point using a printer/terminal attached to the on board computer.

Standard calibration methods are employed for the calibration of the basic aircraft handling and engineering instrumentation.

8 TAIL ROTOR INSTRUMENTATION TECHNIQUES

RAE are, at the time of writing, considering a programme of work on tail rotors to be carried out on the Puma in parallel with further main rotor research.

The provision of systems for the acquisition of data from tail rotors follows the general principles established for main rotors. However, the increased rotational speed and the reduced physical size of the tail rotor require the mass of the sensors and signal conditioning equipment to be minimised. This may be achieved by the use of compact manufacturing procedures, such as hybridisation, both to reduce the size of, and to increase the reliability of, the minimal circuitry which is required.

Perhaps the greatest difficulty in the instrumentation of tail rotors lies in the modification of the blades and RAE are considering the use of a variant of the glove technique to avoid removal of blade material. The experience gained in the aerodynamics of main rotors has been used to minimise the number of sensors required on a tail rotor and it has proved possible to keep the increase in blade mass to an a level commensurate with normal blade weight tolerances. To ensure that dynamic balance is maintained, a complete blade set is to be modified; dummy gloves are to be fitted to the non-instrumented blades in order to ensure that both aerodynamic and dynamic balance is maintained.

9 FUTURE DEVELOPMENTS

The principle of recording data related to blade azimuth position has been carried through all the stages of development which have occurred since the introduction of the earliest equipments and is still the current practice. However with the introduction of analysis software which has been designed to accept data samples at uniform intervals of time and the need to carry out both tail and main rotor experiments simultaneously future systems are to be designed to run at fixed frequency.

In order to synchronise with the sample rate of the RAE digital tape system a data rate design aim of 256K (262,140) samples/sec has been chosen both for main and for tail rotors. This will, if the full capacity is applied, lead to a total rate of 524,280 samples/sec which will relate to typical buffer store sizes of several million samples. Such large volumes of data will require constant attention to the provision of suitable reduction software and revised procedures for storage, transfer, and access during analysis. Database methods have been proposed for the solution of some of these problems and it is clear that powerful data management tools such as these are to be of prime importance to the success of future rotor research programmes.

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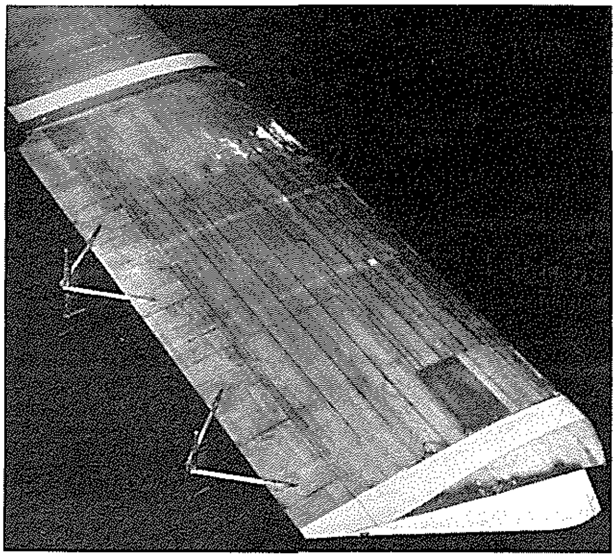

Fig 1 Glove fitted to Wessex blade

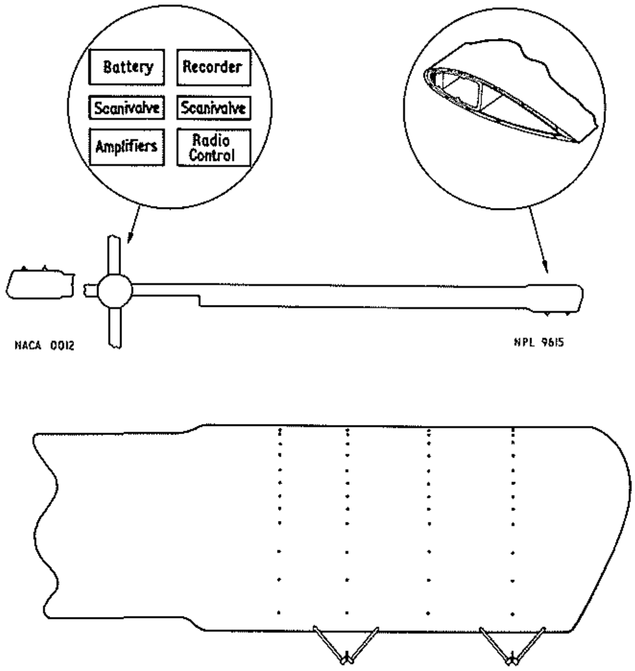

Fig 2 Schematic of aerofoil comparison system

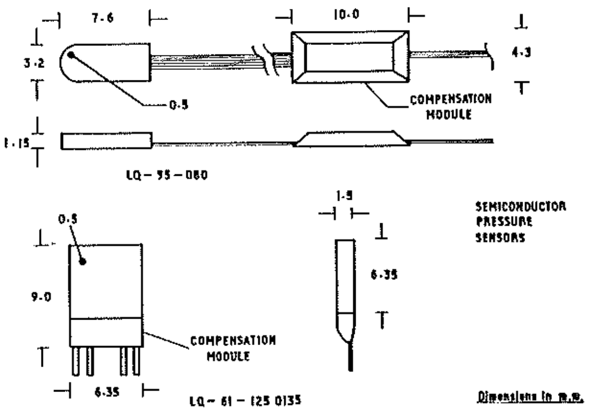

Fig 3 Pressure sensors

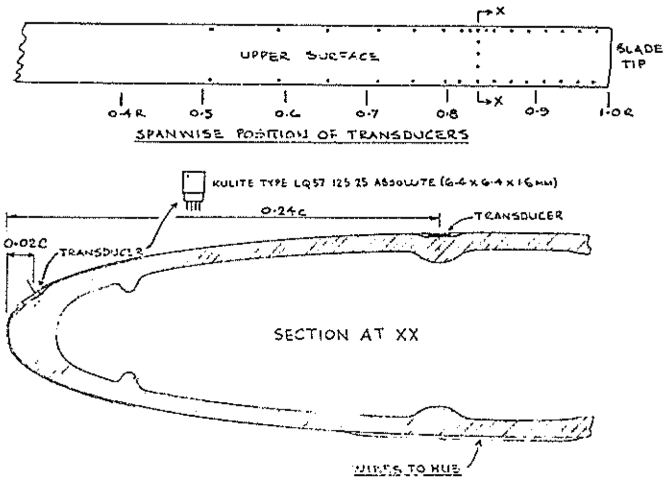

Fig 4 Sensor layout on general research blade

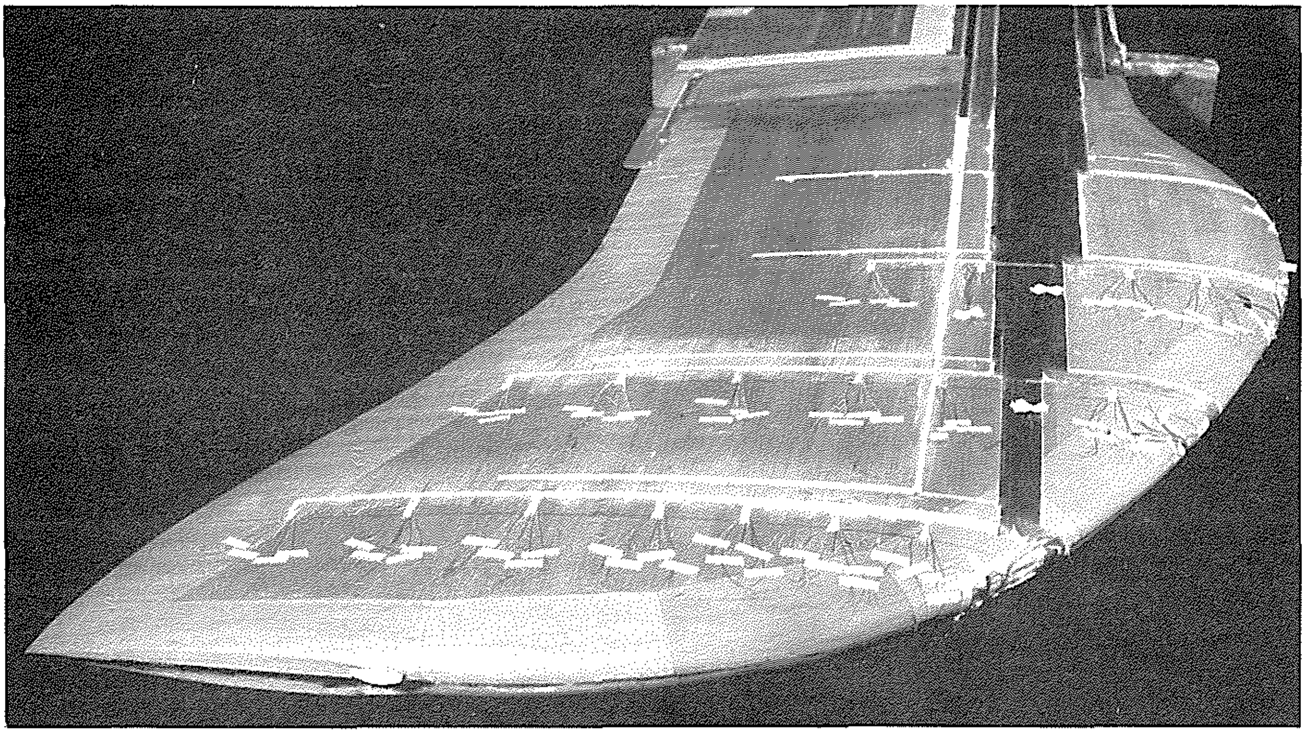

Fig 5 Swept tip glove under construction

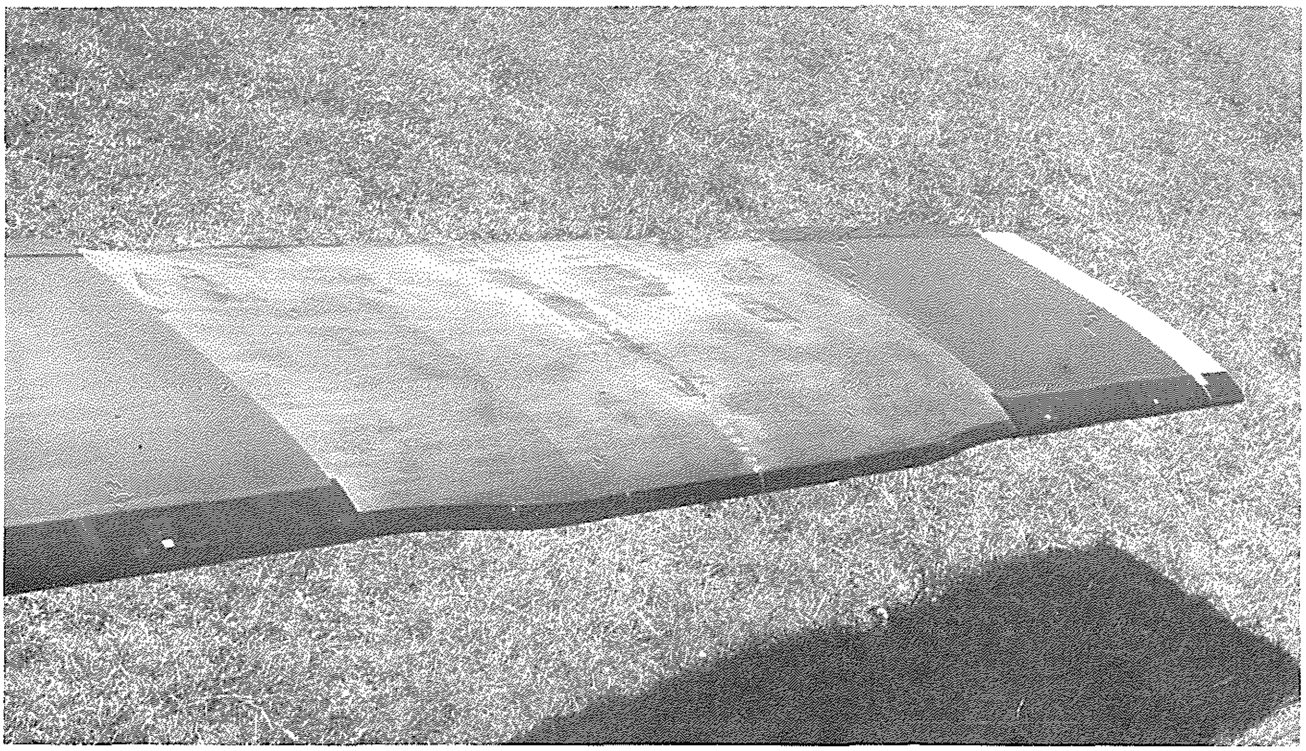

Fig 6 Experimental aerofoil glove section

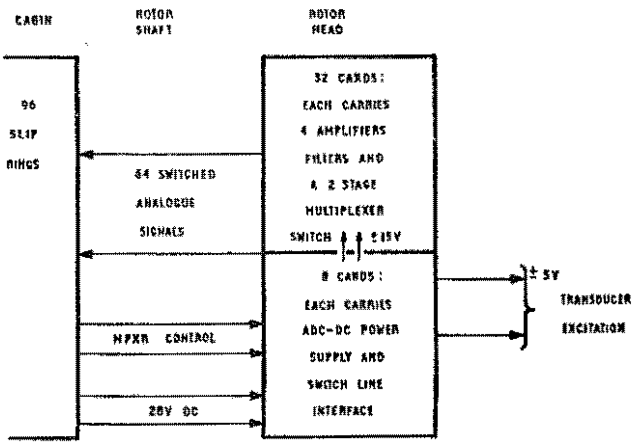

Fig 7 Arrangement of rotor head instrumentation pack

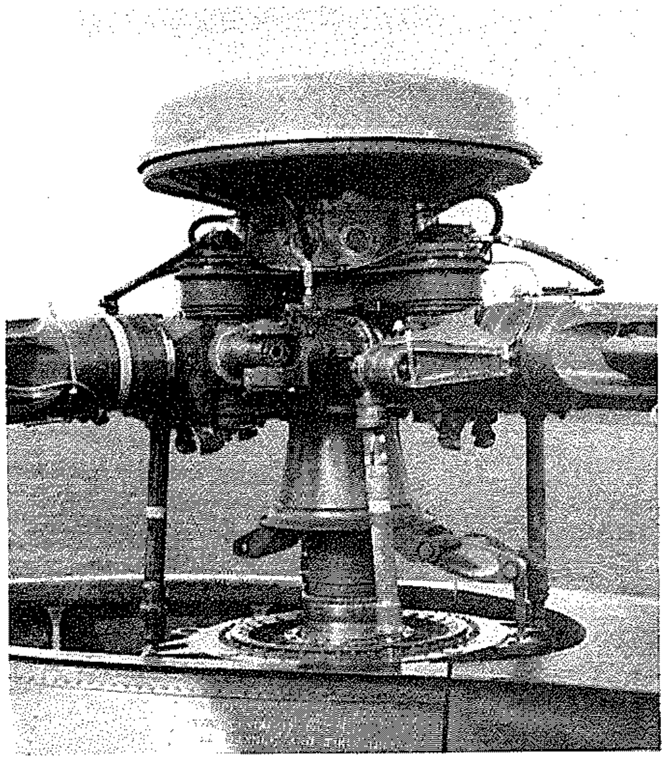

Fig 8 Puma rotor head installation

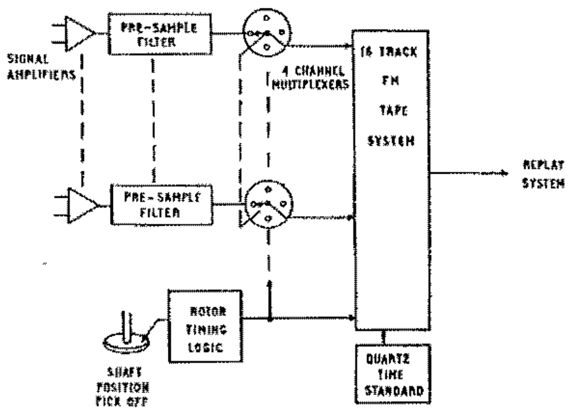

Fig 9 Analogue recording scheme

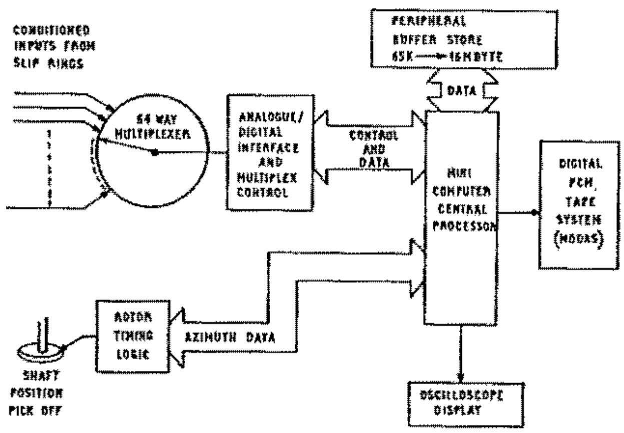

Fig 10 Schematic of digital recording

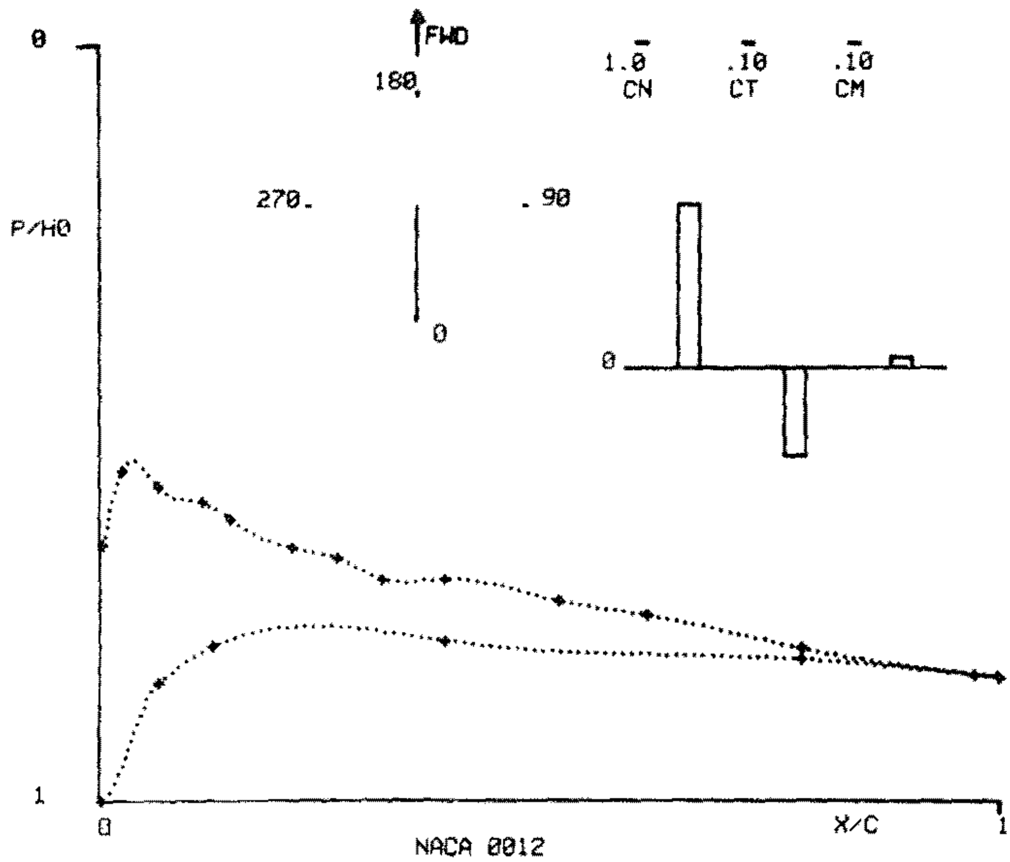

Fig 11 Frame from RPP5 film

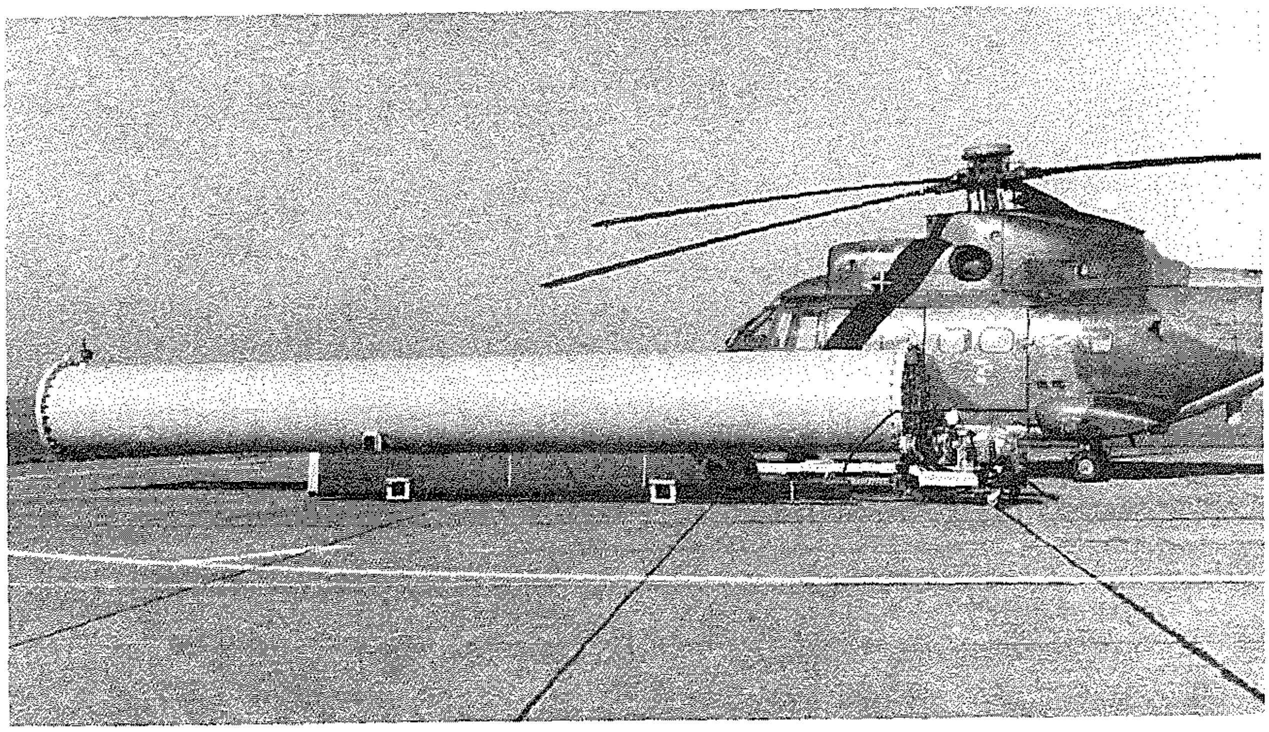

Fig 12 Pressure sensor calibration using the test chamber