ROTOR AEROMECHANICS RESEARCH WITH THE RAE RESEARCH LYNX - THE EXPERIMENTAL FACILITY AND TEST PROGRAMME

P. C. Tarttelin
Royal Aerospace Establishment
Bedford UK

Abstract

This paper describes the instrumentation and flight test programme for the RAE Bedford Lynx, which is to continue and expand upon previous aeromechanics research undertaken at RAE using the research Puma. The aircraft is currently being extensively instrumented, including two of the main rotor blades with pressure sensors and strain gauges respectively to provide aerodynamic and structural dynamic data. Indicator sensors will be used to enable derivation of incidence, blade loading and regions of separated flow, and the structural data will be derived through application of Strain Pattern Analysis. The aircraft instrumentation includes an instrumented tail rotor, a Helicopter Air Data System (HADS) to enable low airspeed measurement, and a Control Input Device to provide a means for injecting pre-programmed control inputs in a precise and repeatable manner. The test programme will include trims and dynamic response in steady and manoeuvring flight to support aeromechanics model validation for performance, loads and flying qualities. The data is gathered using an on-board data recording system, and a suite of programs permits the handling and analysis of the data. A first phase of test flying with this new facility is expected to be complete by March 1991. The paper also reviews the lessons learnt from experience with similar measurements on the RAE research Puma.

List of Symbols

a_0	reference speed of sound (m/s)
b	number of blades
c	blade chord (m)
C_{ple}	leading edge pressure coefficient, $P_{le}/½\rho v^2$
C_{pte}	trailing edge pressure coefficient, $P_{te}/½\rho v^2$
M_t	mean rotor tip Mach number, $\Omega R/a_0\sqrt{\theta}$
n	normal acceleration (g units)
N	local aerofoil normal force (N)
p_c	power coefficient, $P/\rho\pi R^2(\Omega R)^3\sigma$
P	rotor shaft power (W)
P_{le}	leading edge pressure (N/m^2)
P_{te}	trailing edge pressure (N/m^2)
q_c	torque coefficient, $Q/\Omega\pi R^3(\Omega R)^2\sigma$
Q	rotor shaft torque (Nm)
R	rotor radius (m)
t_c	thrust coefficient, $T/\rho\pi R^2(\Omega R)^2\sigma$
T	rotor thrust (N); air temperature (K)
T_0	reference air temperature (K)
v	local velocity (m/s)
V	aircraft velocity (m/s)
α	local Blade Incidence (deg)
θ	temperature ratio, T/T_0
μ	advance ratio, $V/\Omega R$
ρ	air density (Kg/m^3)
σ	rotor solidity, $\pi R^2/bcR$
Ω	Rotor speed (rad/s)

Introduction

During the past fifteen years, the Puma helicopter at RAE Bedford (Fig 1) has been used for a variety of research tasks, including rotor aerodynamics and dynamics, handling qualities, and agility. In addition, the extensive flight test database has been used to assist development of the RAE helicopter model HELISTAB (Ref 1) and the RAE/Westland rotor loads program (Ref 2). During 1984, the Strain Pattern Analysis (SPA) blade was flown to explore blade dynamics (Ref 3) and in 1988, the General Purpose Research Instrumented

Blade (GPRIB), and the instrumented tail rotor were flown to explore both blade dynamic and aerodynamic behaviour over a wide range of flight conditions; results from this test programme have been presented in a number of publications (Refs 4-7). The Puma has now been retired from flying duties, and the research work is being continued and expanded with the Establishment's research Lynx (Fig 2).

The RAE Bedford Lynx flight test programme is a multi-phase activity serving the research of flight mechanics, main and tail rotor blade aerodynamics and dynamics. The aircraft is comprehensively instrumented with inertial and air data sensors, control and actuation sensors, in addition to pressure and strain instrumented main and tail rotor blades. An additional airworthiness strain gauge installation will allow fatigue damage accounting, a vital activity acknowledging the unconventional usage spectrum to which the aircraft will be exposed. This paper details and explains the instrumentation for the two main rotor blades, and outlines the proposed flying programme and planned analysis activities.

The Need

The data collected from the facility will provide an extensive database of results for use in the validation of both the Level 2 helicopter simulation model, being developed at RAE Bedford and Glasgow University (Ref 8) and the coupled rotor/ fuselage model being developed at RAE Farnborough and Westland Helicopters Limited (WHL) (Ref 9). The overall aim of this validation is to provide an improved helicopter simulation capability, which in turn will be used as a development tool for the proposed ACT Lynx programme. The improvement of helicopter simulation models is highly dependent on the knowledge and understanding of the blade environment, which varies significantly both along the radius of the blade, and around the rotor disc. The data obtained from use of the blade-mounted pressure sensors and strain gauges will provide the detail required to support the development of these blade element models, particularly in the areas of blade vortex interaction, advancing blade shock and retreating blade stall, as well as the effects of blade elasticity.

Lessons From The Past

The Puma GPRIB research was innovative in that blade loading and incidence were derived from the pressure distribution given by a radial array of sensors mounted close to the leading edge of the blade (Ref 4). In summary, the technique depends on the correlation of the leading edge pressure measurements with normal force coefficient, C_N , and incidence, α , using a comprehensive look-up table derived from two-dimensional wind tunnel data with suitable allowance made for the various unsteady effects. The method is strictly applicable for attached flow only and the limits of applicability are delineated by the detection of trailing edge pressure divergence (associated with flow separation) indicated by an additional array of trailing edge sensors. A further limitation is the assumption of two-dimensional flow. Experience with the Puma has shown this to be an acceptable assumption for most purposes, and the limitation will be reduced for the Lynx by the inclusion of additional chordwise sensors as described below. Estimates of blade deformation can be obtained using the RAE-developed SPA method (Ref 10), whereby the strain pattern of the rotating blade is related to a set of calibration-mode strain patterns for the non-rotating blade; the resulting relationship is used to synthesise blade deformations.

The Lynx main rotor research programme will also make use of these methods with the installation of an array of leading and trailing edge pressure sensors which will be more extensive than that used on the Puma; in addition the Pressure Instrumented Blade (PIB) will have one chordwise array of sensors at the 85% radius position. This will enable a direct check and adjustment if required, to results from the wind tunnel data used in the derivation of aerodynamic parameters. Experience with the Puma data has highlighted the value in being able to estimate the normal force from the pressure integral especially in the higher Mach number conditions and regions of rapid incidence change, to support the 2-D indicator results. The Strain Gauge Blade (SGB) is also being more extensively instrumented than the GPRIB, and reflects experience with that programme, in that any shortfall in the number of installed gauges leads to unacceptable inaccuracies in the derived deflections. This takes on an added importance with the Lynx rotor system, since it differs from the Puma in being of the hingeless type. The root pitching or feathering motion of each of the main rotor blades is input by means of a hinge, however, the flap and lag components of the motion are elastic. Another difference between the two rotor systems is the rotor blade section profile. The Puma blade section is symmetrical, and remains constant along the whole radius, whereas the Lynx blade section is cambered, with a linear variation of thickness along the radius.

Other improvements in the Lynx programme pertain to the use of repeatable control inputs through use of a Control Input Device (CID), and more accurate attainment of hover and low speed conditions through use of a Helicopter Air Data Sensor (HADS) system.

The following Sections of this paper describe the instrumentation and flight test programme in more detail.

Instrumentation

Data Acquisition

The flight test data are obtained via an on-board data recording system, the elements of which are represented in Fig 3. The main rotor data are passed from the blades through amplifiers on the rotor head before being transmitted in analogue form by slip rings to the main multiplexer. This unit feeds the data in serial form, via an analogue to digital converter, onto the magnetic tape recording system MODAS (Modular Data Acquisition System) in PCM format. An additional microprocessor (MIPROC) performs several functions, one of which is to permit a choice of sampling rate for each channel within a limit of 128 K (12-bit) samples per second. The rotor shaft position pick-off, used to calculate azimuth position and rotor speed, is also fed through the MIPROC to the recorder, but all other data from the fuselage and tail rotor are fed through a Signal Conditioning Unit (SCU) which performs a number of functions. There are several important aspects to take into account when using serially recorded data; definition, filtering, anti-aliasing, and skewness. Each parameter needs to be recorded at a rate which gives a desired data definition; this is related to the expected frequency content of interest of the signal, eg rotor flapping angle needs to be recorded at a frequency far in excess of that needed for the air speed indicator. The data must be filtered to remove unwanted high frequency noise which may contaminate the signal, but this level of filtering needs to be carefully chosen to retain the desired amplitude resolution. For the type of filters employed for the main rotor data, the frequency resolution for a sensor recorded at 1024 samples/sec (the rate to be used for all rotor head data) is 190.36 Hz, relating to the 36th harmonic of the rotor speed. This filtering, along with amplification, takes place on the rotor head and within the SCU for the fuselage and tail rotor. Skewness of data results when all data is assumed to be sampled at the same instant so that maximum skew of rotor related data is about one degree in azimuth; this is minimised by careful arrangement of the data sampling order.

A subset of the data recorded in flight is also telemetered to a ground station so that instrumented structural components, for example, may be monitored during a manoeuvre. The Lynx structure is instrumented with an array of strain gauges for Fatigue Usage Monitoring (FUM), which can be telemetered, all of which undergo post-flight analysis for lifing purposes.

Pressure Instrumented Blade

The PIB is currently being instrumented with an array of 20 leading edge (*le*) and 20 trailing edge (*te*) pressure sensors, the positions of which are shown in Table 1 and Fig 7. The radial spacing of the sensors is no more than 5% rotor radius. The *le* array will be used to obtain estimates of α and C_N using the results of wind tunnel tests (Refs 11 and 12) and supporting theoretical data; the *te* array is used to indicate the presence of stall, as described in Ref 4. The number and positions of the sensors was chosen as a result of experience with the Puma GPRIB programme: the GPRIB had a total of 17 *le* sensors, concentrated toward the tip region to capture the high loadings and effects of blade vortex interaction, but the resulting sparse array inboard, coupled with some gauge failures left a 'hole' in the radial distribution of data. In addition, this blade had only 9 corresponding *te* sensors; some interpolation of these results was made to ascertain whether stall was present at any of the other 8 radial positions. Stall can occur in limited local regions of the blade, and too wide a spacing of sensors can give misleading indications.

It is important that the blade aerofoil section is not modified significantly compared with the original blade (or that used in the wind tunnel tests), to ensure validity of the Indicator Method. The *le* pressure sensors are small and including adhesive, only 0.032 in (0.65 mm) thick, but must be mounted directly onto the surface of the blade since indentation or thickness-reducing of the *le* surface is prohibited by the blade damage tolerance limits. To blend the sensor to the size of the section an anti-erosion-strip (*aes*) fairing is being used. The effect this type of fairing could have on the aerofoil's performance was addressed by Wilby (Ref 13) from calculations using the Viscous Garabedian and Korn (VGK) method (Ref 14). The conclusion of this analysis was that any adverse effects on the aerodynamic characteristics of the section caused by the *aes* can be minimised, or perhaps effectively eliminated, by careful choice of the *aes* configuration, the two main recommendations being:

(1) the rear edge of the *aes* must be faired out as smoothly as possible, perhaps over as much as 10% chord, and

(2) The *aes* must not be faired out until a point aft of the most rearward position of any shock waves. For rotor blade sections at a Mach number of 0.6 where the shock wave becomes important, this is typically at 20% chord. For higher Mach numbers, the shock position is closer to the leading edge.

For these reasons, it was decided to use a fairing of minimum thickness 0.65 mm blended out gradually from 30% chord to 40% chord. An example of the fairing installation for the RAE 9615 section is shown in Fig 4. The blend region will be accomplished by filling with an appropriate medium and smoothing to shape with reference to a template.

The *te* sensors will also be mounted onto the blade surface, at 98% chord, and blended using a filler (Fig 5). The fairing of these sensors is not as critical as for those on the *le*, since the flow in this region is not as sensitive to minor changes in the local shape.

The GPRIB programme gave some confidence in the use of the Indicator Method, but the limits of its use have not yet been fully defined. As mentioned previously, the method is invalid for conditions of separated flow, but the limits of applicability toward the blade tip, where the flow is increasingly both transonic and three-dimensional, needs to be investigated. For this reason, an array of sensors as outlined in Table 2 is being installed around the chordline at 85% radius. This position is outboard enough to experience transonic conditions, but is sufficiently inboard to avoid the harshly three-dimensional environment at the extreme tip. In addition, this is the position at which the blade section is defined as RAE 9615, for which extensive wind tunnel results exist (Ref 11). The resulting integrated pressure distribution will provide values of C_N to compare with those obtained from the sensor at 2% chord, for a variety of essentially two-dimensional conditions, and empirical methods to account for any differences will be sought.

As described previously, it is important to retain as faithfully as possible the shape of the original blade section. However, for the chordline array, a more substantial fairing than that employed for the *le* array is required. There are two reasons for this. First, the sensors are positioned around the surface, and hence the whole blade section must be faired. Second, the fairing must vary in thickness in order to retain the original section profile. In addition, the available sensors are not all of the 0.025 in (0.635 mm) thick type; some are 0.045 in (1.143 mm) thick, and others 1.45 mm thick. The minimum thickness of the fairing selected by consideration of the thickness and location of the sensors gives the overall magnification of the original section required for a similar overlying section. The position of this section in relation to the original is also important; if the aerodynamic centre of the new section were to be significantly far from the original, the blade dynamic response would be affected, and could potentially affect blade stability. The fairing chosen is shown in Fig 6. The original section is increased in size by 7.5%, but the quarter chord position remains the same as that of the original. The fairing will be constructed using balsa wood and filler, again smoothed to shape with reference to a template.

The three-dimensionality of the flow at the tip deserves special attention, and it is known that the load there cannot be determined accurately using the Indicator Method (Ref 7). An array of pressure sensors similar to that employed at 85% radius would be required to obtain this data, but limitations on the capability of the recording system at present preclude the use of such an installation. However, since there is a possibility that the recording capacity may in future be improved, the relevant wiring is being installed.

The changes in the blade planform produced by these installations are shown in Fig 7. The most obvious change is of course the fairing around the chordline, since not only does it extend beyond the size of the original blade chord, but it must also be blended into the planform shape of the blade in general. This blending must be over an area large enough to allow the chordline to behave as an RAE 9615 section in regions of yawed flow such as that experienced at the fore and aft areas of the rotor disc.

In addition to the miniature pressure sensors, a tip pitot is being mounted on the PIB. As well as providing an additional reference pressure, it is intended to process the data to provide airspeed and sideslip angle to compare with results from the air data system.

Calibration of the PIB will be performed in a similar fashion to previous RAE pressure instrumented blades as follows: the blade is inserted into a pressure chamber whilst still wired up to the aircraft instrumentation system, and pressure changes corresponding to the working range of the sensors applied by pressurisation or evacuation of the chamber. A linear characteristic is used to define the sensor output and zero checks are carried out on the aircraft before and after each flight.

Strain Gauged Blade

The number and positions of the strain gauges shown in Table 3 and Fig 8, for installation on the SGB are based on previous experience with the SPA and GPRIB blades. The number used reflects both the desire to capture the dynamic response of the Lynx blade in sufficient detail, and to provide a safety margin to account for the possibility of gauges becoming unserviceable during use. The radial positions for the root elements (hub and dogbone) are required in order to measure the rapidly changing stresses, essential for derivation of the fundamental blade mode deformations; the locations for the blade itself are defined to give a sufficiently detailed distribution of blade deformation (Ref 15).

The gauges are arranged as separate bridges for the local flap, lag, and torsion motions; an example for one radial station is shown in Fig 9. They are adhered directly onto the blade surface, and covered in a paste which when cured remains as a robust but flexible surface. Further protection may be afforded by use of a fairing similar to that used on the PIB *le*; this would also help to limit any differences in dynamic behaviour between the two blades.

Modal calibration of the SGB for SPA will be performed in a similar fashion to that of the Puma SPA blade; details of this process are described in Ref 10, but briefly the process is as follows. The calibration is performed with the blade fitted to the aircraft, since the motion of the hub flexural components are an integral part of the modes. Mode excitation is obtained by a number of electromagnetic exciters located along the blade. Two are located near the blade root operating in-phase for flap modes, and anti-phase for torsion, and one at the blade tip for the lag modes. The calibration mode displacement patterns are measured with miniature accelerometers attached to the blade surface, and the calibration mode strain patterns are recorded via the aircraft data acquisition system. The strain gauge outputs themselves are calibrated by the application of bending/twisting moments to the blade; this avoids the necessity of repeating the SPA calibration during the life of the blade, since any change in the strain gauge outputs will be accounted for by changes in the bending moment calibrations.

Overall rotor balance will be achieved by counter balancing blades opposite the SGB and PIB. The first set of flights using the SGB (but not the PIB) will require balancing with a standard blade; later, the SGB and PIB will be balanced opposite one another. The balancing process is in two stages. First, changes to the blade first mass moment are made by the addition or removal of some of the tip balance weights to achieve static balance. Second, a check on the Tip Path Plane (TPP) motion of all the blades during a ground run; with corresponding small alterations to the blade root pitch angle setting to achieve dynamic balance.

Associated Instrumentation

The aircraft is instrumented to enable recording of all the necessary air data (3 velocity) components, inertial and controls data required to establish the flight conditions flown in the research programme. Pressure altitude is measured by two sensors to give coarse and fine tolerances, in addition to radar altitude. Airspeed is obtained with both coarse and fine tolerances from the aircraft pitots, and also from the HADS. The HADS will be used primarily for the low speed end of the flight envelope. In addition to longitudinal velocity, it also supplies measurement of lateral and vertical velocities, hence sideslip and incidence. The HADS is mounted on the starboard side of the cabin, measuring velocity magnitude and direction with a swivelling sensor which uses rotor downwash at low speed and free stream at higher speeds. The instrument is useful in quasi-steady conditions and manufacturer's calibration data will need to be supplemented with additional data from flight tests at RAE. Normal, lateral and longitudinal accelerations are measured using accelerometers mounted in a fuselage pack, whilst additional accelerometers in the nose and cabin serve to provide roll, pitch and yaw accelerations. Pitch and roll attitudes are obtained from a vertical giro and heading from the aircraft compass; rates about all three axes are obtained from rate gyros. All pilot's control positions and actuator displacements are recorded, as are the inputs applied using an automatic control input device (CID).

The CID enables the use of a pre-defined signal to input a movement to any one of the control actuators, the primary use of which is to provide specially designed and repeatable control inputs. Inputs by the aircraft Auto Stabilisation Equipment (ASE) in the relevant axis may be suppressed, but the size of any CID control input will be limited by the same constraints as for the ASE and the CID can be disconnected at any time.

For the main rotor, all feather angles are measured using a strain gauged cam and follower device, and the rotor speed and azimuth angle measured with a rotor shaft pick-off; rotor torque is obtained from a shaft mounted strain gauge. Tail rotor control displacement and torque are also recorded.

As previously mentioned, an additional set of strain gauges has been mounted on and in the fuselage and on both main and tail rotors for Fatigue Usage Monitoring (FUM). This array of gauges, as defied by Westland, enables measurement and monitoring of the loads on selected aircraft components, both during flight, using the telemetry facility, and post flight. Monitoring these loads during a flight is important for trims and manoeuvres which produce large structural loads, or where conditions are close to the edge of the aircraft flight envelope, to avoid damaging the aircraft and endangering the lives of the crew. Post flight examination of the loads will be conducted to calculate the component life usage. The fuselage gauges are mounted on the collective and cyclic pitch links, the gearbox and engine mounts, and on the fin and tailcone struts and surfaces. Gauges are also mounted on one main and one tail rotor blade. This FUM strain gauge fit forms part of the array of SPA gauges on the instrumented tail rotor and on the SGB for the main rotor.

Flight Trials

Test Points

The test points to be flown vary from conditions of steady hover to fast forward manoeuvring flight; they will be evaluated progressively and the results analysed to check the integrity of the measurements before progressing to the next stage. Initially, the results of steady hovers will be analysed in detail to provide a reference datum for the following flights. These reference cases enable comparison of the blade aerodynamic and dynamic behaviour in different, but related flight conditions, ie the radial distribution of, for example, blade total incidence, could be derived for conditions where all but one of the parameters will be matched. The parameters used to match the steady flight conditions are thrust coefficient t_c, torque coefficient q_c, (or power coefficient p_c), advance ratio μ, mean main rotor tip Mach number M_t and climb/turn/descent rate. The values of t_c and M_t from the hover flights will be used as the target values to obtain in forward flight, for a range of values of μ and q_c; and for a variety of rates of turn, climb and descent.

The primary area of interest in this research is to compare the components of local incidence, including downwash and blade motion, and to map the way in which they change over the flight envelope. Inherent in this activity is validation of the Indicator Method through the use of the chordline results to give the detail required, and integration of the resulting loads to provide rotor thrust and moment as an overall measure of confidence.

Having established a basic confidence from the analysis of steady conditions, the results from the manoeuvres will be analysed in detail. Specific manoeuvres have been chosen to produce an environment of both slowly and rapidly changing rotor conditions; the analysis will cover slow change first to gain a measure of confidence in the derivation methods. Low airspeed transition will include fore/aft velocity reversal and sidestep reversal, eg for the former, from 30 kn forwards to 30 kn backwards; and a transition from take off to hover Out of Ground Effect (OGE) followed by a landing. Translation at the higher speeds and thrust coefficients can be served by acceleration/deceleration between hover and 120 kn for example, and from maximum climb rate to autorotation. The more rapid rates of change will be accomplished through the use of step inputs and roll reversals. The former have been used extensively at RAE for flight mechanics and system identification work, in both hover and forward flight (Ref 16). The roll reversals will be used as a method of achieving roll rates of between 20° and 60° per second.

The step inputs, together with more complex multi-steps and frequency sweeps (Ref 16) will be a primary source of data for validation of the Level 2 helicopter handling qualities model, since particularly the frequency sweeps and other specially designed control inputs, such as the Schroeder input (Ref 17), excite the aircraft over the required wide range of frequencies. An example of a frequency sweep is given in Fig 10; in this case a longitudinal cyclic input on the Lynx. The pilot's control movement is shown, in which the frequency of the input is gradually increased up to 4 Hz over a time of 100 s.

Flight at low speed and in descent still remains a handling problem and limitation in normal operation. It is intended to cover the approach, entry, and recovery from Vortex Ring operation so that the associated handling characteristics and detailed rotor aerodynamic data can be investigated and correlated.

Obviously, all the above test points must be carefully planned and applied with regard to the aircraft performance and structural limits. At RAE, a Flight Trials Instruction (FTI) is prepared by the project officer and agreed with the aircrew to ensure that tests are safe and fall within these boundaries.

Test Methods

The test methods for the various steady trimmed flight cases are similar in that they are all straightforward flight conditions. However, great care and patience are required to trim to the desired parameters described above. In all cases, the trims are performed with reference to the aircraft mass and air temperature, and the desired parameter values achieved through positioning at the appropriate density altitude and using the appropriate rotor speed (Ref 18). Fig 11 shows the type of test chart used. The order of operation is to determine the altitude required to achieve the desired t_c and M_t with reference to the total aircraft mass. Once this point has been established, the rotor speed must be trimmed to achieve the desired M_t. This procedure can be extremely time consuming, and requires great skill and patience on the part of the test pilot and Flight Test Observers (FTO). Aircraft mass is of course continually being reduced by fuel consumption; the effect of this is to require increased altitude, which in turn reduces the temperature and hence the required rotor speed. The rotor speed on the Lynx is controlled by adjustment to the Speed Select Control Lever (SSCL). The standard cockpit rotor speed indicator will not be used as a reference, since it provides neither the detail required (trim required to the nearest rpm unit), nor the most convenient units (displayed as a percentage). The MODAS rotor speed channel, calibrated in rpm, will be output to the MODAS display panel in real time so that the FTO can monitor the trimming quickly and accurately.

For very high thrust coefficients, ballast weights may be carried so that the altitude required for the trim is not prohibitive.

The manoeuvres are handled differently, for the trimming of the rotor is not as important. The purpose of these tests is to examine the changes in the rotor conditions throughout the manoeuvre, although a nominal trim altitude may be chosen to attain similar conditions to those of the steady trims, or the manoeuvre could be performed at the end of a steady trim run. In order to achieve the desired roll rates for the roll reversal, the angles of bank and periods of input must be calculated, although output of the calibrated roll rate could be directed onto the MODAS display panel for monitoring during the manoeuvre. The desired step and doublet input sizes are implemented by use of a cyclic fixture. This can be held against the cyclic control, and movement within the fixture frame limits the size of the control deflection. The steps are input at the beginning of the recording sequence, and the aircraft response allowed to develop until the pilot decides to regain control.

The frequency sweeps are more difficult to implement, since they require great concentration on the part of the pilot in order to increase gradually the frequency of control movement. The FTO counts and the pilot uses this as a guide to the period of control oscillation, until the input frequency reaches the maximum he can control; this typically takes 100 s, and such a recording period is prone to interference from turbulence, other aircraft movements and radio calls. The ASE needs to be engaged for such an input to avoid the divergent motion which would otherwise result from an unstable aircraft like the Lynx. The CID will obviously make the input process easier, since it will simply be switched on and the input signal left to do all the work; this will of course be closely monitored.

Data Analysis

The Research Instrumented Blades ANalysis (RIBAN) package was specially created to analyse data gathered from the Puma GPRIB; Fig 12 outlines the package order of operation, and is described fully in Ref 4. A version of this package is currently being tailored to accept data from the Lynx programme. Briefly, the package uses a set of software tools (MANS - Modas ANalysis System) to convert flight data, which has previously been manipulated onto a Computer Compatible Tape (CCT), into a form suitable for use in a proprietary data display and analysis package. The data is extracted from the CCT in the form of an edit sequence using CONTAP (CONvert TAPe), and the desired channels extracted using EXTRACT. The data can now be displayed using DATS (Data Analysis Terminal System), (Ref 19), and is ready for analysis using a suite of RAE developed Fortran programs. These programs perform the calculations to derive the distribution of C_{ple} and C_{pte}, from which C_N and α are then obtained, including effects due to unsteady aerodynamics. The SPA method is used to calculate the blade deformations, and the two analyses brought together to calculate the components of incidence, including rotor downwash (Ref 7). The experimental results can also be compared to those produced by the RAE/Westland ROTORLOADS prediction program (Ref 2), a version of which has been tailored to suit the format of the data output from RIBAN.

Some examples of the type of data to be obtained are shown in Fig 13. They all show data gathered from the Puma GPRIB programme, which is still undergoing analysis, in comparison with results from the ROTORLOADS program. The flight condition is level flight at 88 kn (μ = 0.23, t_c = 0.08); (a) shows total incidence, (b) total flap displacement, (c) elastic flap displacement, and (d) downwash velocity (normalised by tip speed), for the blade at the 60% radius position. Although analysis of results is not the subject of this paper, it is clear that important differences between these examples of experiment and theory are present, particularly with regard to blade-vortex interaction and elastic motion. These are just two of the areas of detail which will be addressed in the validation of mathematical models.

The level of detail in terms of frequency and spatial distribution required to conduct handling qualities and control studies is continually debated. Tischler recommends that the model frequency range required should be at least 3 times that of the control bandwidth (Ref 20). The extent to which blade aeroelastic modes contribute to fuselage dynamic motion for the Lynx is a research topic in the present programme. The lowest frequency elastic blade modes, dominated by flap and lag motion will be essential as these are transmitted as regressing modes in the fuselage co-ordinate system. Beyond these, the first harmonic components of higher modes may be important in some situations. Furthermore, in defining the limits from a manoeuvre standpoint, the blade behaviour following stall and blade-vortex interaction are important, requiring the kind of detailed strain and pressure distributions defined.

Concluding Remarks

Two of the main rotor blades of the RAE research Lynx are currently instrumented with pressure sensors and strain gauges respectively. The Pressure Instrumented Blade is being fitted with a leading edge and trailing edge array of pressure sensors for estimation of incidence and loading using the Indicator Method and, in addition, will have a chordline of sensors at 85% radius to be used for validation of the method, particularly in transonic flow. A further chordline may be installed in the future to obtain the tip loads, and the relevant wiring is being placed for this purpose. The blade will be faired so that the section remains similar to that of the uninstrumented blade and the wind tunnel section from which the reference loads used for the indicator method are taken. The Strain Gauged Blade will have a radial array of strain gauges oriented to respond to flap, lag and torsion stresses, and the Strain Pattern Analysis method used to obtain the deflections. The measurements of pressures and strains, together with the aircraft motion velocities, rates and attitudes obtained from a comprehensive instrumentation fit will be recorded in flight and processed by a suite of programs to derive blade loads and the components of blade incidence. The latter comprise the separate effects of blade angle variation including elastic pitch and flapping, together with the rotor inflow and induced velocity components. The derivation of the inflow distribution is one of the most important aspects of the programme of work; a knowledge of this distribution across the rotor disc will indicate which of the downwash model structures are most suitable for use in a helicopter handling qualities model. In Ref 6 an empirical correction to Momentum Theory for hover downwash was made based on Puma data of this type, and gave an indication of the type of improvements that can be made to simple models. A wider range of results from both Puma and Lynx data is aimed to provide a validated generic model to be developed. This paper has outlined the technology of the experimental facility and discussed the scope of the flight research. The first phase of experimental flying is expected to be complete by March 1991.

Table 1

Radial positions (%R) of leading and trailing edge pressure sensors for the Pressure Instrumented Blade.

Leading and Trailing edge
35
40
45
50
55
60
65
70
72
75
78
81
83
85
87
89
91
93
96
98

Table 2

Chordwise location (%c) of the chordline pressure sensors on the Pressure Instrumented Blade.

Upper Surface	Lower Surface
0	
0.5	
1	1
2.06	
3	
4	4
6	
10	10
15	
20	
	22
30	
	46
50	
	68
70	
90	90
98	

Table 3

Radial location (%R) of the strain gauges on the Strain Gauged Blade.

Flap, Lag, and Torsion
3.2
5
6.8
14.2
17
19.6
25
31
41
48
64
74
85
96

References

1 G. D. Padfield. "A Theoretical model of helicopter flight mechanics for application to piloted simulation." RAE Technical Report 81048, 1981.

2 C. Young. "Development of the vortex ring wake model and its influence on the prediction of rotor loads." AGARD CP 334, 1982

3 A. R. Walker, D. B. Payen. "Experimental application of strain pattern analysis (SPA) - wind tunnel and flight test results." Paper 79, 12th European Rotorcraft Forum, West Germany, 1986.

4 M. J. Riley et al. "Estimation of rotor blade incidence and blade deformation from the measurement of pressures and strains in flight." Paper 110, 14th European Rotorcraft Forum, Milan, Italy, 1988.

5 Lt S. Baldwin, C. S. Handley. "Flight tests to explore tail rotor limitations in the low speed envelope." Paper 111, 14th European Rotorcraft Forum, Milan, Italy, 1988.

6 S. S. Houston, P. C. Tarttelin. "Theoretical and experimental correlation of helicopter aeromechanics in hover." RAE Technical Memorandum FM 20, 1989.

7 P. C. Tarttelin. "Rotor loadings in hover - correlation of theory and experiment." Paper 19, 15th European Rotorcraft Forum, Amsterdam, The Netherlands, 1989.

8 A. Simpson. "Derivation of modal Lagrangian equations of motion for a multi-blade flexible rotor on a flexible shaft." RAE Technical Report 1990. (In preparation).

9 P. T. W. Juggins. "Application of the Westland CRFD program to total helicopter dynamics." Paper presented at the AHS Specialist Meeting on Rotorcraft Dynamics, Arlington, USA, 1989.

10 A. R. Walker. "Experimental determination of rotating helicopter blade deformations using strain pattern analysis." RAE Technical Memorandum MAT STR 1108, 1988.

11 R. H. Landon. "Results of quasi-static and ramp tests on the RAE 9615 section." ARA Ltd Model Test Note M161/4, 1986.

12 R. H. Landon, C. Humphries. "Results of quasi-static and ramp tests on the RAE 9617 section." ARA Ltd Model Test Note M161/5, 1986.

13 P. Wilby. RAE Private Communication, 1979.

14 M. R. Collyer. "An extension to the method of Garabedian and Korn for the calculation of transonic flow past an aerofoil to incloude the effects of a boundary layer and wake." RAE Technical Report 77104, 1977.

15 A. R. Walker, "RAE Bedford flight research Lynx helicopter. Suggestions for SPA transducer positions." Unpublished RAE note, MS2 TN ARW/08, 1987.

16 G. D. Padfield (editor). "Applications of system identification in rotorcraft flight dynamics." Vertica V 13 No 3, pp 229, 267, 281, 343, 403, 1989.

17 P. Young, R. J. Patton. "Comparison of test signals for aircraft frequency domain identification." Journal of Guidance, Control and Dynamics V 13 No 3 p 430, 1990.

18 G. D. Padfield. "Flight testing for performance and flying qualities." AGARD Lecture Series No 139 'Helicopter Aeromechanics' Paper No 7, 1985.

19 G. W. Foster. "A system for analysing flight trials data." RAE Technical Memorandum FS(B) 672, 1987.

20 M. B. Tischler. "System identification requirement for high bandwidth rotorcraft flight control system design." AIAA Journal of Guidance, Control and Design, August 1990. (To be published).

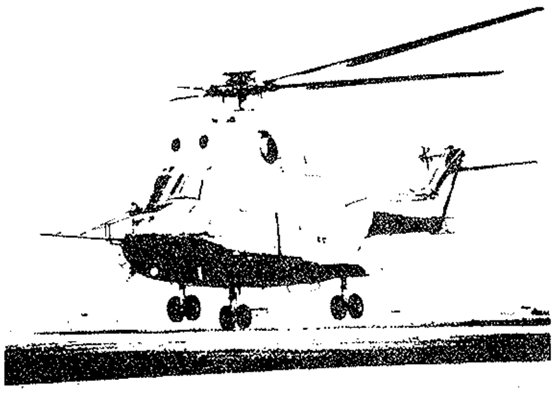


Fig 1 RAE research Puma

Fig 2 RAE research Lynx

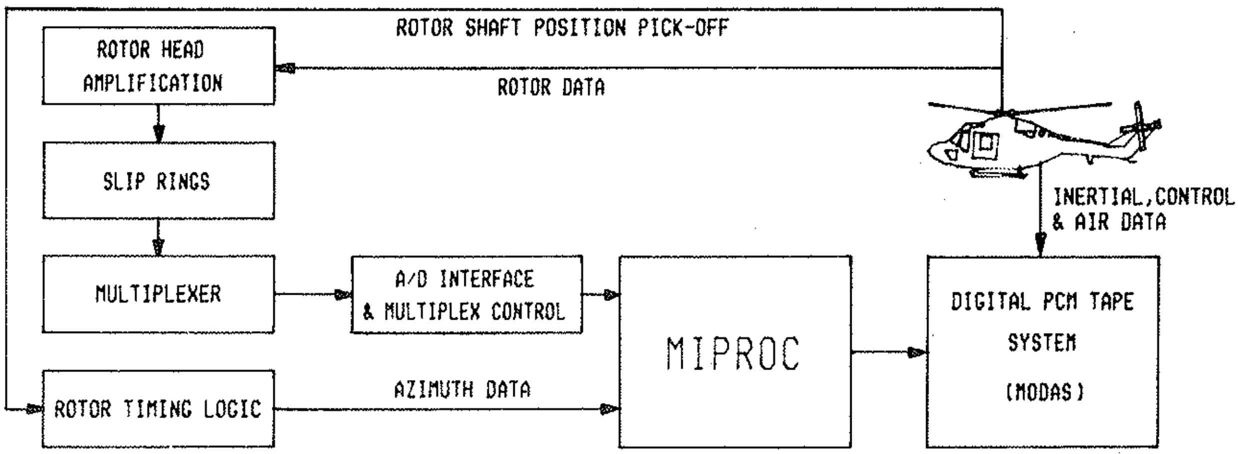


Fig 3 Schematic of data acquisition on research Lynx

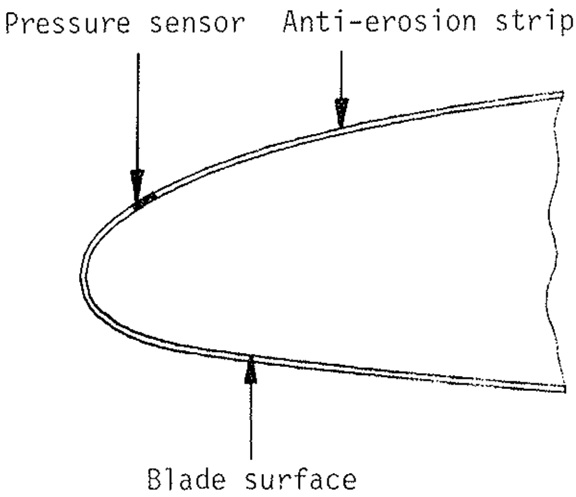


Fig 4
Leading edge sensor installation

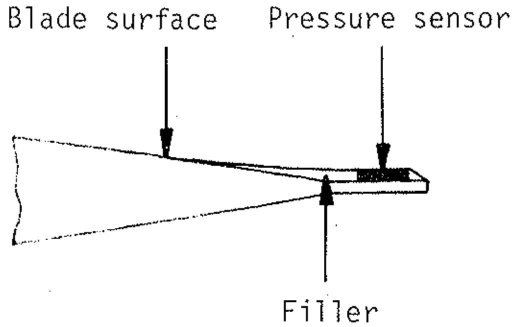


Fig 5
Trailing edge sensor installation

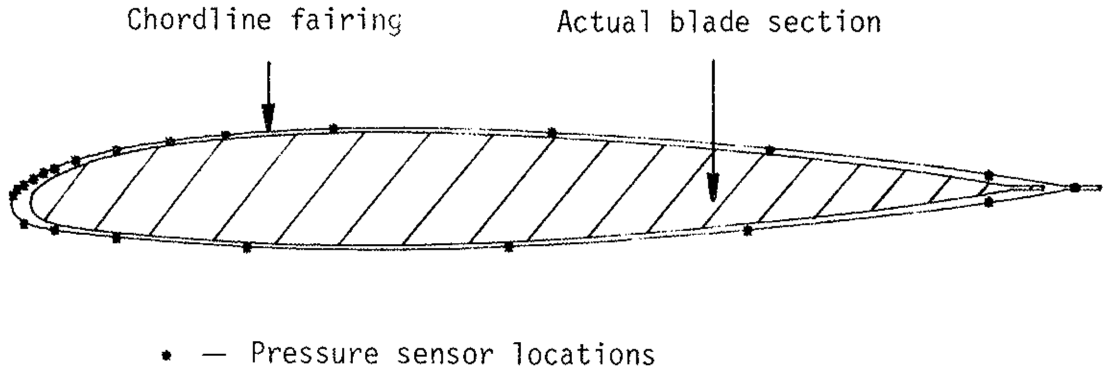
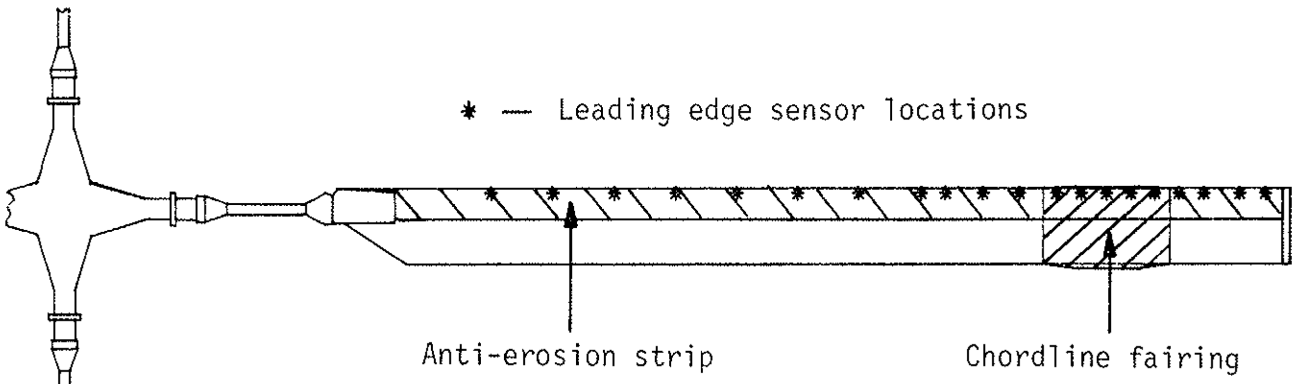


Fig 6 Chordline fairing at 85% radius



(trailing edge sensor locations and trim tabs omitted for clarity)

Fig 7 Pressure instrumented blade planform

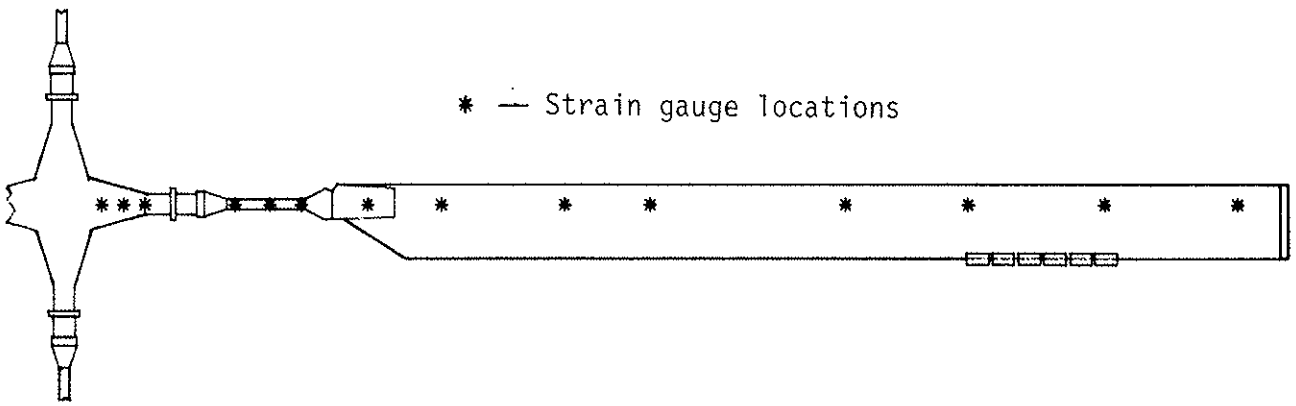


Fig 8 Strain gauge blade planform

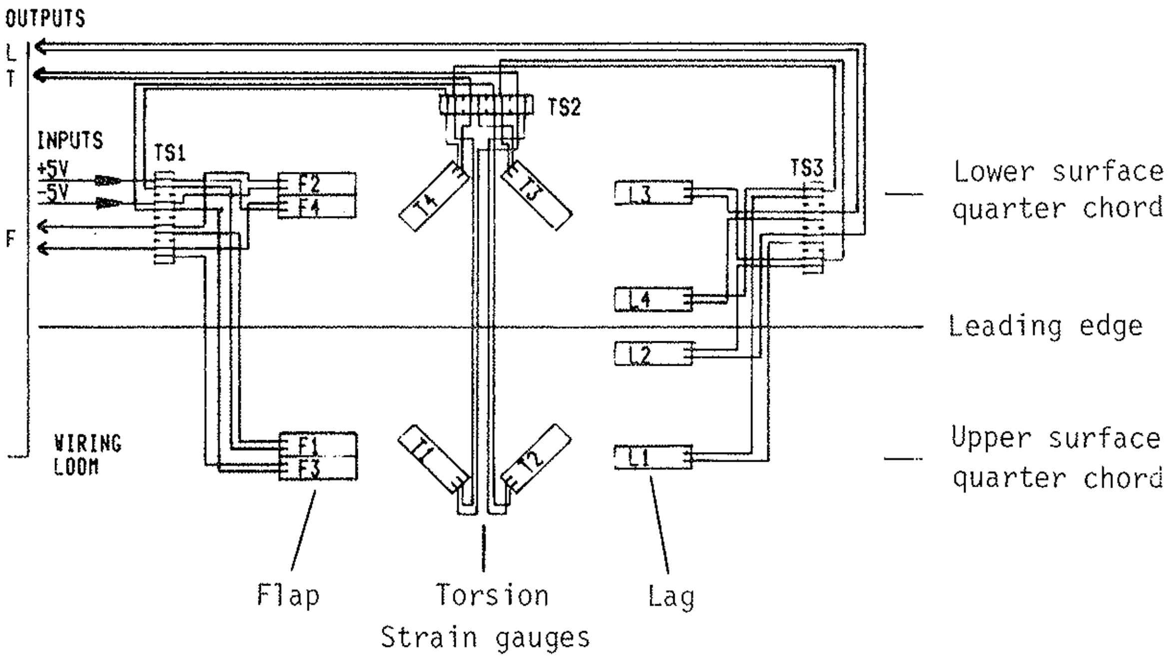


Fig 9 Strain gauge layout for each radial station

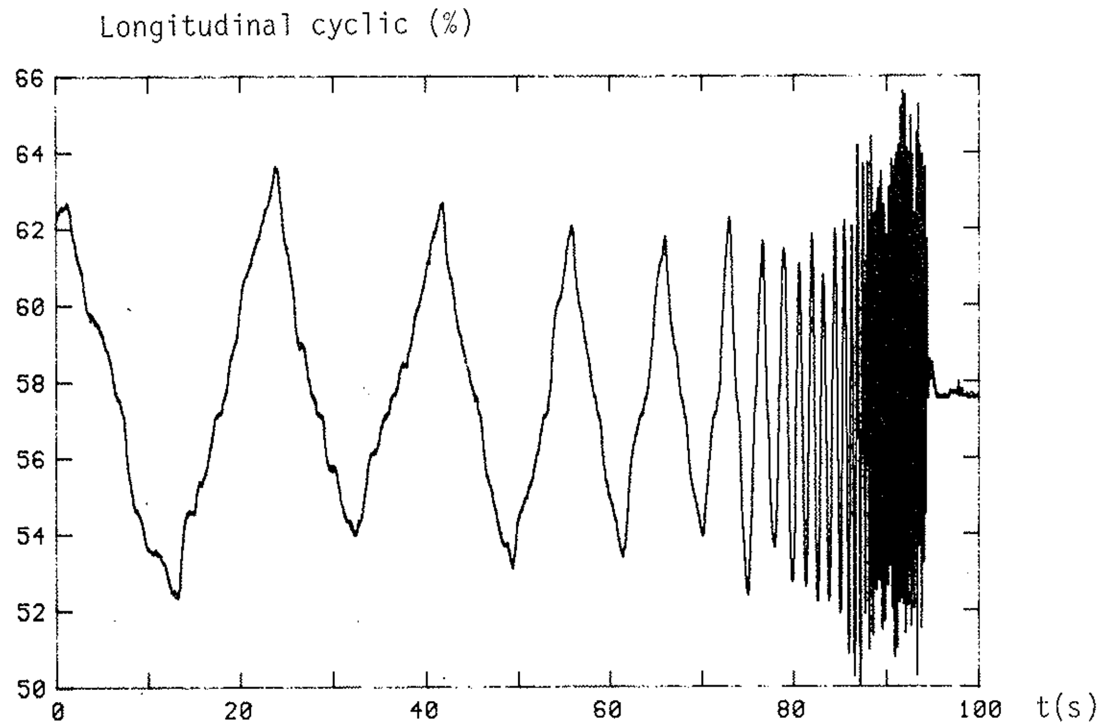


Fig 10 Lynx ZD559 - longitudinal cyclic frequency sweep

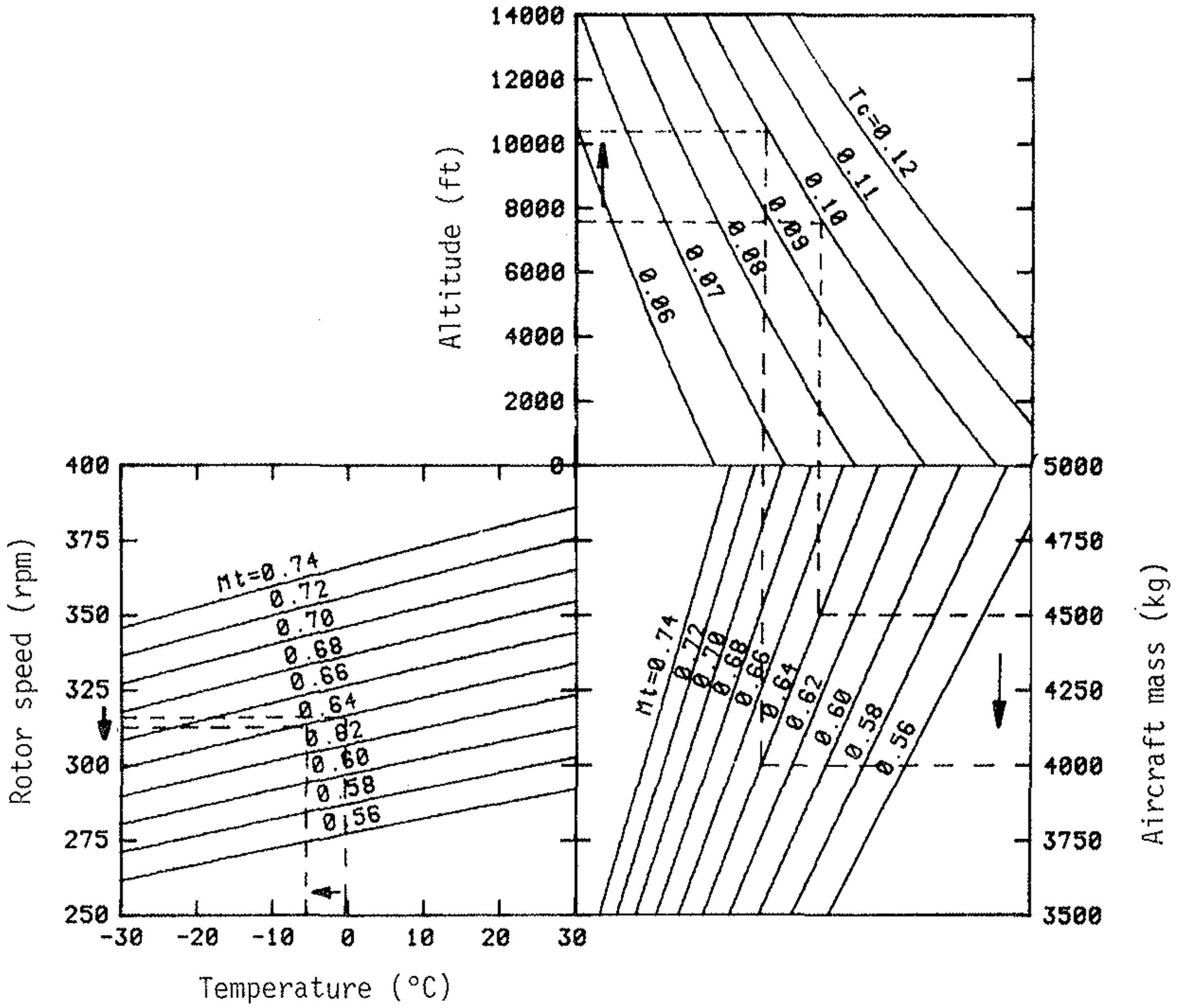


Fig 11 Lynx test chart

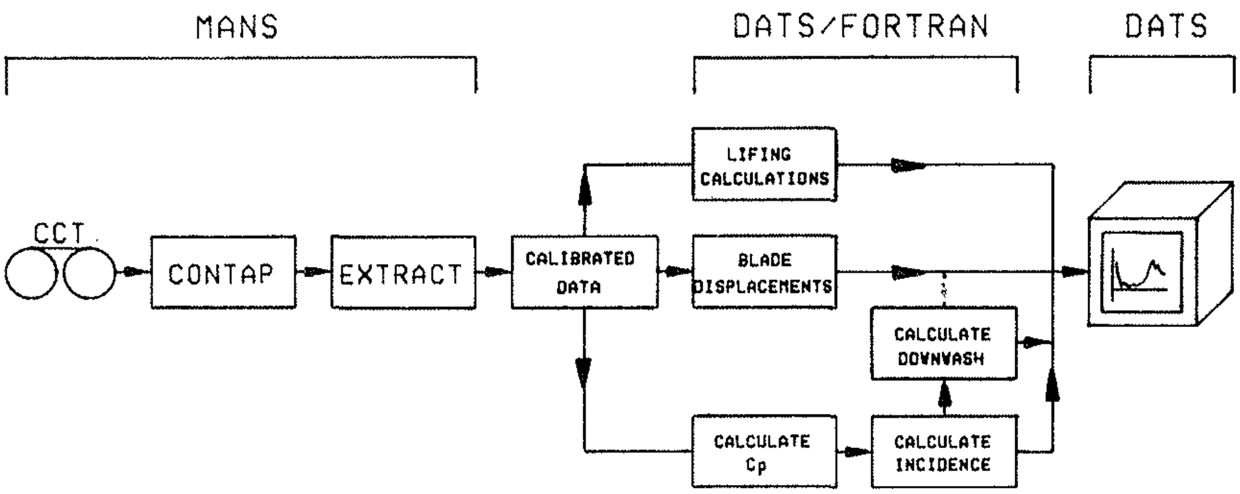


Fig 12 Elements of RIBAN package

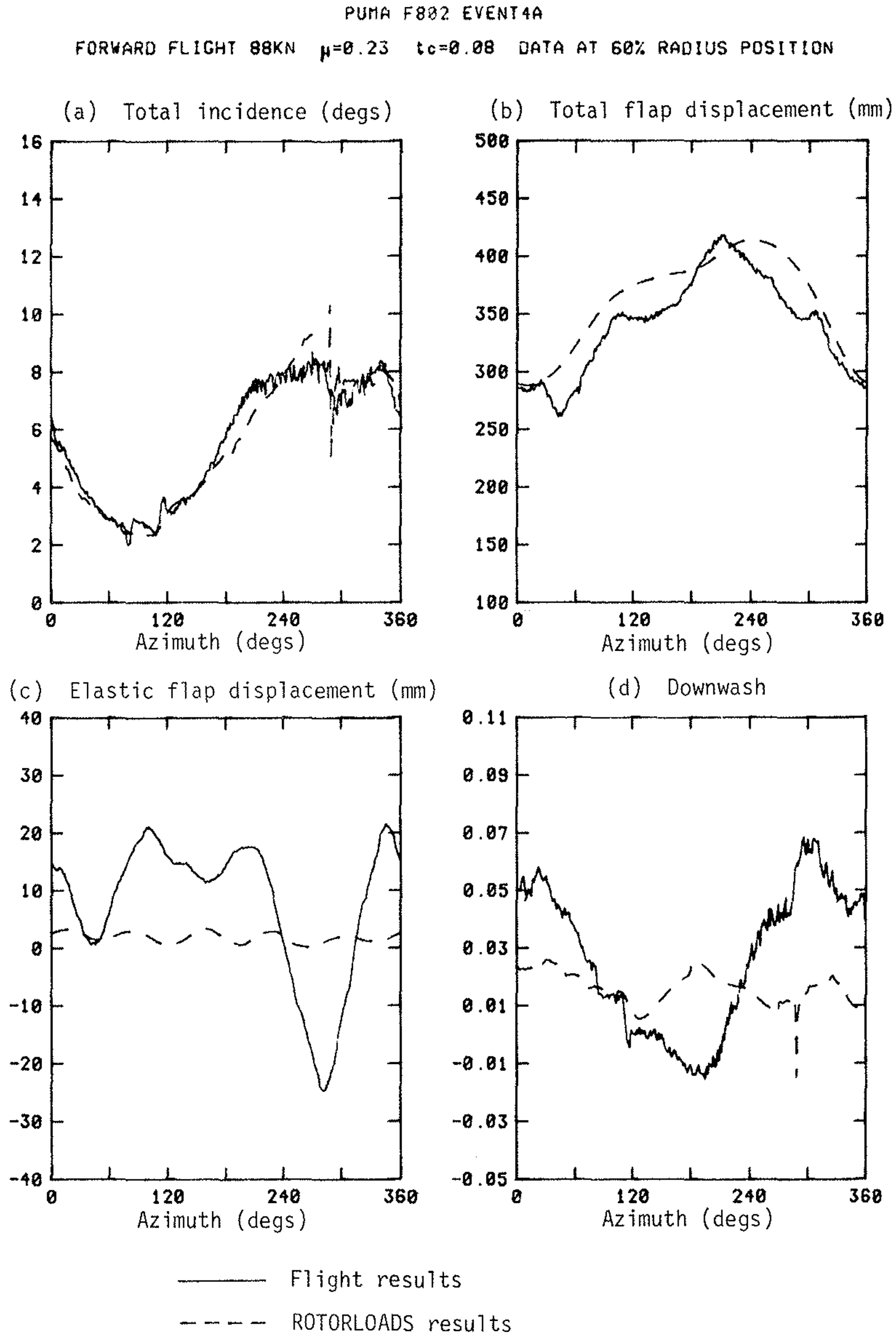


Fig 13 Puma XW241 - comparison between flight results and theory