SIXTH EUROPEAN ROTORCRAFT AND POWERED LIFT FORUM

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A REVIEW OF SOME TOPICS OF UK RESEARCH ON HELICOPTERS

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ABSTRACT

The progress in some topics of British research on helicopters over the last decade is reviewed. Special attentention is given to aerodynamics, structural dynamics and all-weather operation.

1 Introduction

As we enter the new decade it seemed useful to look back at some of the British research in the helicopter field over the last ten years and, perhaps,to try to set some goals for the coming decade. In half an hour it is not possible to do more than offer a few examples of the work but, even so, I should like to take time to point out the scale of the achievements in earlier decades.

If we look back to the dawn of rotary wing aircraft in Britain, we find that in 1920 Louis Brennan was engaged in the design of his helicopter. This remarkable aircraft made some 70 flights before the inevitable crash in 1925. The complexity of the control system for its pair of rigidly mounted wings was at the heart of its problems but this was valuable in emphasising the wonderful simplicity of Cierva's hinged blade system used on his autogyros. Cierva was consequently encouraged to develop his concept and, by the end of the decade, he had introduced lag hinges and had produced a practical flying machine. In the meantime Glauert had produced his fundamental work on rotor theory which formed the basis of so much that followed.

In the next decade the aerodynamic and structural properties of rotary wings received close attention so that by 1939 the theoretical background to design had been well established. This had been successfully applied to the design of an autogyro type which saw service through most of the second world war and also to the demonstration of the promising Weir Helicopter in 1938.

After a period of dormancy during the war, rotary wing research in Britain was re-awakened by the introduction of the Sikorsky R-4 into service in 1945. An intense period of research followed, particularly in stability and control, and the full potential of the rotary wing was explored. For instance, the Fairey Gyrodyne appeared in 1947 and by the following year had captured the world speed record for helicopters.

In the 1950's the problems of automatic flight control systems were tackled and much emphasis was placed on the techniques of operating helicopters from ships at sea. A diversity of new designs entered service and the Fairey

Rotodyne appeared as a prototype civil transport which raised the world speed record to 191 mph.

One of the most interesting products of the 60's was the Circulation Controlled Rotor, a concept which is only now being brought into fruition in the United States. The design processes of conventional helicopters were also being developed at this time as, for instance, in the first detailed modelling of the rotor wake. There were two particular developments which determined the course for the 1970's. These were the emergence of large scale computing for the thorough prediction of rotor behaviour and, on the international scene, the arrival of composite materials as a practical means of constructing rotor blades. The first fruits of the former were seen in dealing with the design problems of the Lynx with its semi-rigid rotor. By 1971 the Lynx had flown and confirmation of the soundness of the design principles was available.

So much had been achieved in this and earlier decades, what were the 70's and the 80's to bring? The rest of the paper deals with some selected topics on this theme.

2 Blade aerodynamics

The performance of helicopters in the past had been severely restricted by the need to minimise the peak-to-peak oscillatory loading in the pitch controls; consequently a symmetrical aerofoil section, usually NACA 0012, was adopted almost as a matter of course. But with the Lynx came a blade which was aerodynamically tailored to provide more lift on the retreating side and delayed compressibility effects on the advancing side. This indicated the need to make more use of the three dimensional possibilities of blade design. In this we were encouraged by the versatility that the new composite materials could provide in blade construction. Thus freed from the constraints of manufacture we asked ourselves what performance advantages could be expected if reasonable, though not necessarily minimal, control loads were permitted. By the end of 1973 it had been established that the performance limitations on both the advancing and the retreating sides could be pushed out to give a potential 50% increase in the thrust available from a rotor of given size.

The quest for higher maximum lift coefficients for the retreating side was pursued. This was supported by transonic wind tunnel tests on two-dimensional sections, first in steady conditions and later in oscillatory conditions to represent the flow on the blade in forward flight more accurately. Some results from these oscillatory tests were presented by Wilby in the 1979 Forum. He showed that it was possible to design sections which not only give a much larger maximum lift coefficient but which also provide a greater delay in stall in the appropriate unsteady conditions. This result has now been confirmed in flight tests on a Puma, using the "glove" technique. We are now able to optimise the variation of aerofoil section along the blade to take advantage of these higher lift coefficients over most of the blade whilst thinning the section towards the tip to minimise compressibility effects.

Considerable further reduction in compressibility effects can be achieved by using sweep at the tip. The use of large scale computing has made it possible to make calculations of the pressure distribution at zero lift in steady conditions in order to provide carefully shaped tip planforms to reduce compressibility effects without upsetting the torsional loading. Some progress has also been possible in the calculation for a lifting tip and for the unsteady effects of the rapidly changing Mach Number on shock position and strength.

3 Rotor loads analysis

In the 60's rotor loads were calculated by a program that was similar in concept to contemporary Sikorsky methods. It used a representation of the blade as a series of strip aerofoils in two-dimensional flow whose characteristics were stored in a look-up table. To represent the influence on the shed vorticity of other blades, a simple line-vortex filament model was used. The dynamics of the blade were represented by using normal modes of the rotor in a perturbation of steady coning. As tested against the only available flight data of the time - the S58 data of Scheiman - it showed only a moderately good performance(Fig 1). Even so the calculation needed considerable effort and lengthy computer runs; but the way to further progress had been indicated.

In the last ten years the program has been gradually developed to take account of the results of research. The local inflow representation has been modified in two important ways. Firstly the simple line vortex model has been replaced by a series of circular vortices displaced downwards and backwards to better represent the shape of the real wake. Secondly the significance of the upwash effect of the fuselage has been recognised and included in the program.

Realistic data for the new aerofoils are included and allowance is made for incidence variation effects. A recent description of the dynamic stall has also been included so that operation close to the rotor limits can now be analysed credibly.

The dynamic model has been extensively revised. The modal analysis now includes a representation of segments of blades which are skewed relative to each other so that three-dimensional effects can be represented. In addition, the use of such modes in conditions significantly different from the datum ones of steady coning requires the inclusion of correction terms due to cyclical effects. First corrections to the linearised equations of motion are included as a program option.

The competence of the present-day program is illustrated in Fig 2, which shows the comparison with recent flight results from a Lynx. With the Lynx there is significant modal coupling so that a comparison of blade loads is more exacting than with the S58. At the extremes of flight, the comparison is markedly better than with the S58; the lag is much better predicted and the flap loads are in good agreement. The pitching loads are better, but not yet altogether satisfactory.

The rotor systems coming into use today differ from those of ten years ago in two main ways. Firstly the further progress towards a bearingless system has led to the separation of the flexural and centrifugal load carrying inboard elements and to the creation of an elastomeric feathering bearing. Secondly the trend towards three-dimensional design will result in blades which are more fully aeroelastic than those of Lynx. The program has therefore been modified to include split load paths but this has yet to be confirmed against test. The blades will operate with aeroelastic coupling of pitch/flap/lag likely to be stronger than that of earlier rotors. Both these features put an added premium on the way in which the blade modes are calculated and the way in which the blade is modelled in the program.

4 Experimental methods

As we have seen, an important element of research in this field is the provision of reliable experimental data to indicate the nature of the mathematical modelling required and to validate the methods as they develop. It is traditional in aerodynamic research to resort to model tests in wind tunnels to perform this function and this is often extended to cover the aeroelastic problems as well. Although, as we have seen, wind tunnels are used to provide the basic aerofoil data for our helicopter work, we have found that the testing of model rotors in wind tunnels to be both time consuming and limited in scope. Building a model rotor scaled for shape, stiffness distribution and mass distribution for operation at representative tip Mach Number and at a reasonable Reynolds Number is an undertaking that we can only afford when there is no proper alternative. Fortunately the advances in data handling techniques during the decade have made it possible to make detailed studies on real blades in flight; surface pressures, blade motions and surface strains can now be measured in great detail and in a very short time so that we no longer have to be concerned by the possibility of the conditions changing during the experiment. Typically it is possible to record 10,000 data points per second and to process them into a state in which they can be readily analysed. Brotherhood reported on a recent example of this work at the 1979 Forum but I make no apology for showing a revised version of his film on this occasion to emphasise the significance of his technique.

The film shows an animation of the pressure distributions along a spanwise line close to the leading edge of a blade as it rotates in flight. The pressures indicate the spanwise loading as affected by the wake from the preceeding blades. The animation of the measurements is preceeded in the film by a sequence illustrating the geometry of the wakes.

Wind tunnel testing will still, of course, be required when it is not practicable to provide airworthy modifcations to a flight blade but, even so, the problems in designing a safe wind tunnel model are not inconsiderable.

5 Dynamic instabilities

Ten years ago, instabilities such as ground and air resonance were understood, but the means of avoiding them - by adding damping forces in the rotor system - were crude, and had drawbacks such as added weight, drag and servicing costs in the rotor hub area. The incentive to avoid lag dampers was strong, but success could only come from an ability to avoid the instabilities in the design stage combined with a much improved capability for accurate stability assessments over a range of flight conditions. A series of research programmes using scaled helicopter models provided experimental data against which theory was checked, and, where necessary, improved. Fig 3 shows a typical comparison of experiment and theory within a region of instability. The result of this work has been to provide a sound theoretical base for accurate stability prediction which can be used with confidence for the next generation of rotors where suitable dynamic coupling will ensure the elimination of lag dampers and their attendant problems. Whilst it is true that other forms of instability - such as flutter of rotor blades and tail rotor instabilities - have received much less attention here than ground and air resonance, there have, nevertheless been theoretical advances which have led to much less reliance being placed on the rule-of-thumb design methods. This is only partly true of 'buzz' and 'bang' tail rotor instabilities though current research with both experiment and theory should lead to complete avoidance of these phenomena within the next decade.

6 Vibration

There have been significant improvements in methods of dynamic testing and response analysis since 1970. Many of these have been generated in the general structural field, but have important applications in helicopters. The most notable development has been in using the computer to fit mathematical models to response measurements, so that subsequent manipulation of response data can be made in terms of analytical expressions rather than raw measurements. The full potential of developments in this area of "system identification" have not been realised in helicopter dynamics. Nevertheless, research has demonstrated that measured dynamic characteristics of an airframe represented analytically, can be used in the design of an airframe appendage, such as a store carrier, so as to achieve dynamic compatibility between airframe and carrier.

The cynic may remark that as helicopter technology develops, the problem of vibration gets more difficult. In a sense he would be right because ten years ago technology development was centred on improving the aerodynamic performance; a succession of improvements was accompanied by corresponding increases in vibration levels until it was appreciated that vibration was, in fact, limiting the performance. This realisation put vibration reduction near the top of the priority league, and has resulted in great expansion of research effort in all aspects of the subject. Whilst it would be ideal to be able to minimise rotor forcing at the design stage, this is inevitably a long term aim, requiring, as it does, a capability for predicting accurately every facet of blade structural and aerodynamic behaviour. Great improvements in capability have already been made, but more will be required to tackle rotor-induced vibration successfully at source. In the meantime, effort has gone into devices for vibration attenuation. The last decade has been notable for research into vibration absorbers, isolation devices and systems, as well as into structural tailoring aimed at minimising vibration. Some success has been achieved, and a good example is the GFRP-based rotor-head absorber developed by WHL. The absorber has no mechanical parts and requires no maintenance. In this respect it is a useful advance on previous head absorbers.

One aspect of vibration that has made enormous strides in the decade is vibration health diagnosis - that is, to use vibration signatures to diagnose faults. The power of the computer to carry out a series of analysis processes on a vibration time-history and to present the answers for comparison with standard data within a few seconds has opened the door to significant savings in the cost of ownership. The main application is currently on gearboxes and similar equipment, but extension to rotors is not far away.

7 All-weather operation

I have discussed some of the work in support of the design of the vehicle and I will now take an example from the work which bears on the operation of helicopters. I have already mentioned the work in earlier decades on automatic flight control and on the operation from ships at sea but it seems to me that one of the most significant areas of advance in Britain in the last decade is in the development of helicopter avionic systems to extend the all-weather capability. Possibly the most important of these advances is the development of image intensifier and infra-red systems to allow low level flying.

In terms of operational utilisation, the most successful night vision system developed to date has been passive night goggles. These are self contained helmet mounted devices containing miniature image intensifiers. They provide adequate performance for a pilot to fly in starlight conditions, and with the advent of the next generation intensifier, this operational capability will be extended to overcast starlight conditions. One of the early difficulties associated with their operational use was the viewing of cockpit instruments, where normal instrument lighting needed to be dimmed almost to extinction to prevent overloading the goggles. Fig 4 shows a system that has been developed which largely overcomes the instrument viewing problem by a complementary filter and shared aperture principle. This separates the largely near-infra-red radiation of the outside world from the cockpit lighting which is designed to be nearer the blue end of the visible spectrum. This is achieved by means of a red filter fitted to the objective which contains a small concentric blue-tinted close-up lens at its centre to accept the blue instrument lighting from the cockpit.

Ultimately the performance of devices such as night vision goggles is limited by the aperture of the optics and intensifier combination which can reasonably be mounted on a pilot's helmet. Extensive development has occured over a number of years on various forms of night vision sensor which overcome this problem. The development of the image intensifier ISOCON low-light television came in the mid 1970's. It was found feasible to fly a helicopter at very low altitude in light conditions below those of overcast starlight using a low-light camera externally mounted feeding a head-down panel-mounted display in the cockpit. With the advent of forward-looking infra-red systems, it has been possible to extend the operational all-weather capability still further. The main limitation of the fixed sensor is the inability of the pilot to scan the scene but this has been overcome in the visually-coupled helmet-mounted display.

In this system the sensor is mounted on a platform in the nose of the helicopter. Its line of sight is directed remotely by the pilot's head position by means of an electromagnetic or infra-red angle detection system mounted in the cockpit. The output from the sensor is fed to a cathode ray tube display mounted on the pilot's helmet so that, as he moves his head, the sensor platform follows. By this means he is presented with a continuous view of the outside world up to the limits of freedom of the platform. Because of the elevation freedom provided by the platform the pilot can, in effect, look through the floor of the helicopter. This can be very advantageous during hovering. Apart from the sensor information , instrument and navigation information is also presented on the display, so that the complete piloting task can be undertaken without the need to refer to other instruments.

8 Conclusions

These examples make it clear that technical progress over the last ten years has been rapid and significant. There are many other subjects, such as research in noise reduction and in the control of icing, where one could demonstrate similar advances. The practical application of much of the work I have described will appear when the Westland WG34 aircraft is built.

What of the next ten years? Research in rotor aerodynamics will provide design methods for tip shapes which can greatly improve performance or reduce the noise generated. The improvements in the analysis of blade structural dynamics will provide reliable design methods for blades which will distort under loading in such a way that performance can be improved or vibrational forcing reduced. Indeed further improvements of the same kind must surely come from the application of Active Control Technology to higher harmonic pitch control as well as improved stability characteristics. To cope with the vibrational forcing that remains we can expect that active isolation systems will be fitted to airframes which are already vibration-optimised. Furthermore vibration health analysis will be making a major impact on maintenance costs. The most rapid advance in avionics is likely to be in the development of integrated systems based on multiplex bus technology using fibre optics. This will involve flight control, radio, engine control, fuel management and the transmission of video signals.

The ultimate test, which only requires the stimulus of a genuine and viable requirement, will be the application of these principles to the development of practical advanced rotorcraft of the kind now being pioneered in the United States.

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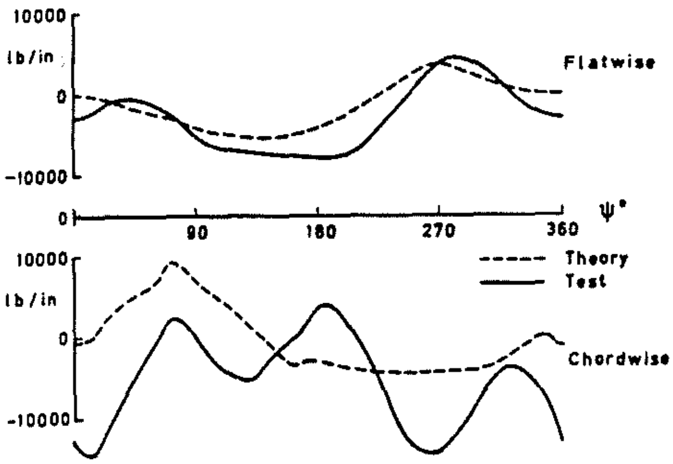

Fig 1 Bending moment prediction - S58

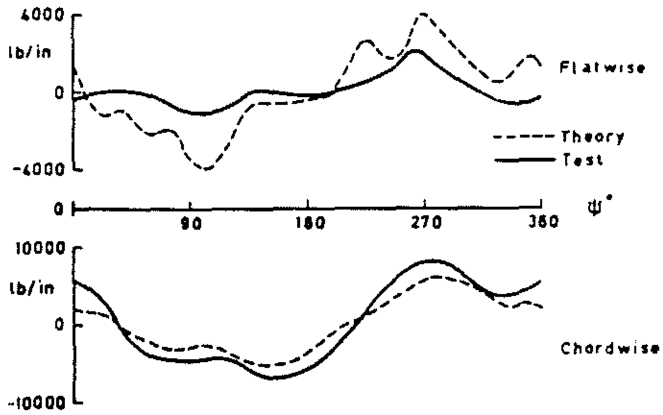

Fig 2 Bending moment prediction - Lynx

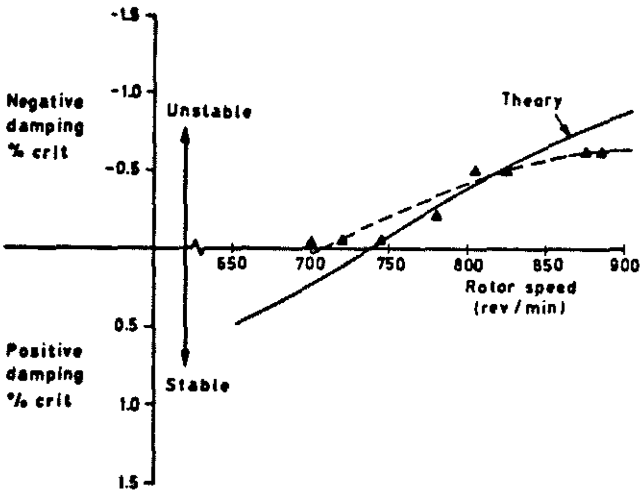

Fig 3 Ground resonance instability at 12^{0} collective pitch

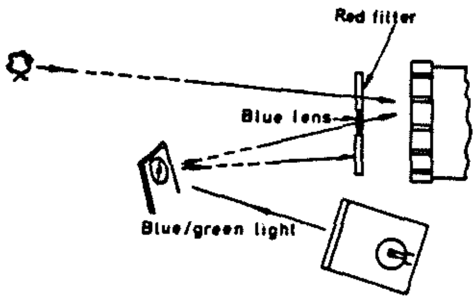

Fig 4 Shared aperture system for viewing instruments