CAP 491

Review of helicopter airworthiness

Report of the Helicopter Airworthiness Review Panel (HARP) of the Airworthiness Requirements Board

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FOREWORD

by John Dent CBE
Chairman of the Civil Aviation Authority

This Report was prepared at my request by a Committee of the Airworthiness Requirements Board. The ARB is a body of distinguished and experienced men from the air transport and aviation industry to whom the CAA looks for advice on airworthiness matters. The CAA values advice and consultation with the ARB.

The UK has a concentrated operation of civil helicopters, in a public transport role, in the North Sea and in these operations a very good safety record has been achieved. However, with that in mind, and also the possible expansion of the role of helicopters in public transport, it seemed to me timely to consider whether, using the latest technology, it was possible to design helicopters to meet enhanced standards of airworthiness.

The ARB Report confirms the good safety record achieved by helicopters but suggests ways in which their safety could be further improved. The Report has been considered and has been fully endorsed and supported by the Board of the Civil Aviation Authority. We realised, however, that to make it fully effective the United Kingdom cannot act alone in respect of all its recommendations.

Three elements can be perceived within the recommendations of the Report. Two of these - some short-term retrospective measures aimed at making improvements to existing helicopters, and some research and development work - are within our practical and domestic capability and will be pursued as rapidly as possible.

The third element - longer term enhancement to existing airworthiness standards which will affect the next generation of helicopters - can only be practicable with international co-operation.

The scene is set by the Report in a most effective way. To make real progress in building on its conclusions, the Civil Aviation Authority will be seeking the support of other airworthiness authorities, particularly those in the group supporting the European Joint Airworthiness Requirements and in the United States of America. We will also be seeking the support of, and consulting with, helicopter manufacturers and operators. In pursuit of these objectives the CAA Board decided to publish the HARP Report and to give it a very wide circulation, both in the UK and overseas, to all interested parties.

In accepting the Report my Board expressed its gratitude to those who had contributed to it and, in particular, to Dr Hugh Conway who took on the formidable task of leading the team who prepared it.

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9/21/AO4C 4 April 1984

Mr J Dent CBE
Chairman
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Dear Sir

In December 1982 you wrote to my predecessor George Hislop. You suggested there was a need to review Helicopter Certification standards to ensure they fully reflected the state of the art in terms of design philosophies, manufacturing techniques and the availability of new materials.

My Board's response to your request for advice was to set up a special group known as the Helicopter Airworthiness Review Panel (HARP) and this Panel recently completed its work. The Panel's conclusions are set out in the Report which I now have the honour to submit.

My Board considered this matter at its meeting on 22 March 1984 and I am to state that the Report has the full support of ARB which formally endorsed all the HARP's recommendations.

I should like to emphasise the following points:

1. The Report is written primarily from the standpoint of engineers and the Panel concentrated on matters related to airworthiness. However the Panel did not ignore the operational aspects of safety.

2. With regard to the formal certification requirements which apply to helicopters as a class, the aim should be for British standards to remain closely aligned with those of the USA and of the manufacturing countries in Europe. Unfortunately this policy - which is widely supported - may inhibit progress because of the extensive consultation involved. Giving advance notice of our intentions could yield some improvement.

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3. Due to the features inherent in all modern helicopters it is much more difficult to provide fail-safe designs than with conventional aeroplanes. Consequently in the Report, attention is drawn to the particular importance of damage tolerance and condition monitoring.

4. The extreme conditions frequently encountered when operating helicopters in the North Sea will sometimes require special measures which cannot reasonably be imposed on helicopters as a class.

The nature of my Board's advice to your Authority is not usually disclosed to the public; nevertheless I believe in this case that the Report should be published. It takes time for agreement to be reached on new formal requirements and even longer in the normal course of events for the effects of these to be reflected in the helicopters actually in service. By publishing the Report we hope it will influence and be of some benefit to those concerned with new helicopter projects. The sheer good sense of what the Panel recommends and the technical challenge which many of those recommendations represent, could prove to be more persuasive than the progressive application of mandatory requirements - which is the conventional approach.

Finally in asking you to receive this Report, I commend to you the Members of the Panel especially Dr Conway for their work. I believe you will share my view that they have made an extremely valuable contribution to helicopter safety.

Yours faithfully

W J Strang

W J STRANG
CHAIRMAN
AIRWORTHINESS REQUIREMENTS BOARD

A REVIEW OF HELICOPTER AIRWORTHINESS

HELICOPTER SAFETY

REPORT OF THE HELICOPTER AIRWORTHINESS REVIEW PANEL

1. Introduction

The Airworthiness Requirements Board was asked, in a letter dated December 22, 1982 from the Chairman of the CAA, to review existing requirements for public transport helicopters and to make recommendations for improved safety standards. The Board asked its Technical Committee to set up an appropriate Panel consisting of its members, already widely experienced, and co-opting others with additional experience and skill in helicopter matters. The precise terms of reference for the Panel are given in Appendix I and the composition is given in Appendix II.

The Panel has not considered in detail the practical problems of changing formal international or domestic requirements. It chose to fulfil its task as engineers assisted by experienced pilots, seeking to state what it considers should be good practice, having regard to present knowledge. We discuss this aspect in detail in the Report. We believe that this has been an important approach to our work, since the Western World's helicopter industry is an aggressive and competitive one where rapid progress in some areas is more likely to be made from market forces than by regulation which of necessity takes time to introduce. Changes to requirements there must be, but they should be based on international agreement which of necessity involves time and can seldom be implemented retrospectively.

On the other hand, we know from our experience in the design of aircraft that there is rarely a simple optimum solution to a given problem and any recommendations we may make must leave room for the creative skills of aeronautical engineers which have brought commercial aviation to its present successful levels.

We believe that a series of accidents in recent years, some related to North Sea operations, was the reason for the request to the ARB; no doubt a contributory factor was the realisation that helicopter operations for urban transport, or general short range pasenger work, are in their infancy, and seem set to expand enormously. In any event it seemed timely to review the present and likely future position.

2. Preliminary Note

The helicopter is a relatively new flying machine whose evolution may be said to have begun with the first Sikorsky machines evolved during the 1939-45 war. Military demands for the Army and Navy have greatly spurred its development, the Vietnam War having given much impetus especially to the larger troop carrying machines. The small helicopter has proved a convenient transport and is widely used, for example, by the business community.

In spite of considerable development funding of vertical or short take-off aircraft of many types, no substitute for the helicopter with its ability to take-off and land without the use of a runway, has been evolved so far. The one exception is the military fighter (the Harrier) - a solution clearly not yet adaptable for conventional passenger transport duty.

The use of helicopters in offshore oil operations has been of fundamental significance. It is difficult to imagine, for example, how Britain's exploitation of North Sea oil could have been achieved so successfully without these machines. The reliability and safety of these operations, while perhaps falling short of those of conventional passenger transport, have been of a high order, and the task could not have been achieved by any other type of flying machine.

Nevertheless, it must be acknowledged that, if helicopters are to extend their operations into areas where they can compete with fixed wing aircraft their inherent safety and passenger facilities and comfort, noise and vibration levels must be improved. There seems little likelihood, however, that they will ever manage to operate "over the weather", emphasising the need to operate in instrument and icing conditions.

Conventional aeroplanes have achieved their present excellent level of safety in the 80 years of their evolution by structural refinement combining knowledge of flight loads and means of dealing with metal fatigue, together with the multiplication of mechanical components (eg engines) or of systems, such that particular failures can be tolerated during a flight.

Duplication or redundancy of much of the critical mechanism of a helicopter cannot, however, be achieved, certainly with present knowledge. There can only be a single lifting system and very little of the rotor or transmission machinery can usefully be duplicated, although the engines themselves can and are. Thus other methods must be introduced if the hazards of mechanical failure are to be avoided. Fortunately, many of the types of failure encountered in machinery occur gradually, meaning that it is possible to detect them by failure warning systems, the so called health or condition monitoring. The development of new and improved techniques here must be an essential process in the improvement of safety of helicopters, as we outline later in our report.

3. Requirements and the International Scene

Airworthiness Requirements for aeroplanes are dominated by those of the Federal Aviation Administration in the USA. This follows from the correspondingly dominant position of their airframe makers (Boeing, Douglas, Lockheed et al). Britain has always had its own procedures controlled initially by the independent Air Registration Board and later by the CAA with the advice of the Airworthiness Requirements Board. Recently considerable efforts have been made to harmonise European requirements under a "Joint Airworthiness Requirements" (JAR) procedure so that British, French, German, Italian, Dutch and Scandinavian authorities share a common code.

Although the JAR code has some differences from FAR and each country may have its own "National Variants", it is inevitable that the lead or dominating code for conventional aeroplanes is American.

In the case of helicopters, however, the European position is much stronger, undoubtedly due to the strong industrial production achieved mainly in France, Italy and Germany, and to a rather lesser extent in the UK. We give some impressive statistics about the size and output of Aerospatiale, Agusta, Messerschmit-Bolkow-Blohm and Westland in Appendix III.

We have noted during our various discussions and visits a great willingness on the part of the American Authorities to collaborate with their European counterparts, and their manufacturers in establishing a common code for helicopters. While this may to some extent be a result of the successful penetration into US markets of European helicopters, and a tribute to the technical competence of their manufacturers, we can only welcome and applaud it. Nothing is likely to contribute more to improved safety than joint international activity aimed at improved requirements, an activity in which the UK must play an active role.

Although establishing a common airworthiness code for helicopters will largely involve harmonising the provisions of the various existing codes, there are areas where much new work needs to be done. One such area covers helicopter handling where a comparison with the corresponding provisions for fixed wing aircraft shows up the helicopter requirement in unfavourable light.

4. The United Kingdom Fleet and its Operations

4.1 The fleet on the UK Register consists of 526 helicopters which includes the following numbers and types of helicopter:

(a) 374 light helicopters (under 2300 kg) mostly used for private, business, crop spraying etc. purposes. (Mostly single engined).

(b) 12 helicopters over 2300 kg (not on public transport) of which 4 are twin-engined.

(c) 140 public transport twin-engined helicopters over 2300 kg.

4.2 Operational activities for public transport

We have excluded from our considerations small machines used for pleasure or personal (usually business) activity. There is a number of taxi or charter operators and business users, however, using small machines, most of which are indeed certificated in the Transport or Aerial Work categories.

The most significant operations for the larger passenger carrying machines are by British Caledonian in the Heathrow-Gatwick shuttle, and British Airways to the Scilly Isles, and by several operators in off-shore oil work (e.g. from Aberdeen). The North Sea operation is by any standard a remarkable one involving regular transport of crews and equipment over long sea distances, often in difficult flying conditions and with very unpleasant sea states, and landings on small areas: it achieves what no other form of air transport could accomplish. Indeed we do not think it likely that all-year-round support for platforms by sea transport would be possible.

4.3 Utilisation

Whereas some conventional transport aircraft regularly exceed 4000 hours utilisation per annum, helicopters even in intensive operation as in the North Sea, rarely exceed 1800 hours per annum.

Small helicopters used for business or charter work average about 300-400 hours a year. We have been informed that the typical military utilisation is also about 300 hours a year.

Accordingly, we noted that it will take appreciably longer to build up flight experience with new types of helicopters than with their conventional counterparts.

4.4 Navigation and Control

Most helicopter operations within the UK Flight Information Region take place outside regulated (controlled) airspace. Although air traffic management arrangements do exist to separate traffic as far as possible, and radar services are provided in some areas, helicopters are operated subject to the Rules of the Air and, in particular, rely on the pilot's vigilance in applying the principle of "see and avoid" to other traffic.

Helicopters operating in regulated airspace are usually required to conform to - or harmonise with - the rules and procedures adopted for the population of fixed wing air traffic, particularly in the vicinity of airports.

5. Accident Statistics

Although helicopter operations in the UK, most of which have been to oil rigs in the North Sea in recent years, have achieved a high level of safety, a number of recent accidents no doubt occasioned the formation of the Panel.

One of our first tasks was to study the available statistics and to attempt to relate the accident rates for helicopters to those for fixed-wing aircraft. We recognised that it may be argued that it is inappropriate to make this comparison because conventional aircraft cannot perform the operations which helicopters undertake (eg, land on a platform in the North Sea). However, there is no other yardstick available and we devoted our efforts to making the comparison as relevant as possible.

One problem is the relatively short average stage flight time of helicopters; in North Sea operations the average flight time is about 30 minutes. Thus the normal presentation for airworthiness purposes of accident statistics as an hourly rate is seen to be unfair to helicopters when compared with fixed-wing public transport operations and a comparison on the basis of the risk per flight would appear to be more realistic. On the other hand the hourly rate has been accepted for a range of aircraft types whose individual average flight durations have varied from fractions of an hour to over 3 hours. In broad terms the average flight time for the larger helicopters is not very different from 1 hour and is roughly the same as that of the commuter type operations with the smaller public transport aircraft. Furthermore if city-centre to city-centre operations with helicopters develop the average flight time for these larger helicopters can be expected to increase and to approximate to that for fixed-wing operations. Thus the Panel felt justified in using the hourly rate as the main basis for comparison for present purposes but this might require reconsideration if the pattern of helicopter usage shifted substantially.

The figures show that very roughly the fatal accident rate for the larger helicopters is about 5 times that of public transport aircraft compared on an hourly basis; this difference is about halved when the risks per flight are compared. An important point which emerges is that in the case of helicopters a much higher proportion of notifiable accidents is attributable to airworthiness causes. Of these airworthiness accidents a far higher proportion prove fatal on helicopters than on fixed-wing aeroplanes (roughly 30-50% as against 10-20% for fixed-wing).

Another point which appears is that a helicopter which enters civil operations without the benefit of having first been developed for and having experienced military service (note that most civil helicopters have been developed from military versions) or from a basically similar type suffers a very high accident rate initially in service and again this is mainly due to airworthiness causes.

The foregoing evidence in our view fully justified the formation of the Panel and supports action aimed at improving the safety standards of helicopters. The flying times of helicopters in public transport operations or their equivalent are building up rapidly and the number of accidents occurring is becoming statistically relevant to the airworthiness requirements; thus it is timely to determine acceptable target levels of fatal accident rates with which any revision of the requirements can be associated.

This procedure of determining target safety levels for various eventualities or failure of particular parts of an aircraft may have little meaning to the designer trying to find an optimum solution to some engineering problem "on the drawing board", but has been found to be an excellent discipline to enable thought to be concentrated on the important areas and to avoid over-design in others. Thus we support the CAA in present proposals to increase their work on the definition of target levels of safety for helicopters.

Although the above broad conclusions from the information of accidents were available to it, the Panel approached its task without too much regard to the subtleties of statistics; however, it records in Appendix IV some of the statistical evidence in more detail.

We did obtain one important piece of information during our trip to the USA which has been confirmed from an examination of UK data - namely that roughly 60-65% of all helicopter accidents are due to "human error", in general "pilot error". While there are some who, pointing out that the same occurs in the case of conventional aircraft, dismiss this as inevitable, the Panel feels that this indicates that the pilots have problems which require resolution, or at least alleviation, by what technology might be able to offer. Are we expecting too much of the pilots? Can we back them up with devices or additional displays to lighten their load, or warn them of danger? We make some comments on the potential in paragraph 8.6, but noting that the problems may well be common to fixed-wing aircraft pilots, and requiring ergonomic or psychological study as well as technical, we make our first Recommendation.

RECOMMENDATION 1. That the CAA initiate a special study into the detail causes of the significant number of helicopter accidents attributed to "human error" to see where technology might contribute to useful improvement.

6. The Reliability of Helicopters

When considering the safety of conventional fixed-wing aircraft it is possible to distinguish between safety and reliability. If the engines of a 4-engined transport are not reliable the aircraft can still be safe, although the cost to the operator will be high (perhaps the argument is not so strong on twin engine transports). Most if not all other vital equipment on aircraft is duplicated or even triplicated or quadruplicated. Thus in approving requirements the ARB is not primarily concerned with reliability as such. In the case of helicopters, at any rate within the present state of the art, the position is quite different. "Safety and reliability are highly correlated", to quote an experienced airline engineer.

The Panel has examined much available data on failures of helicopter equipment, and has reviewed the causes of accidents with the Accident Investigation Branch of the Department of Transport. We illustrate the situation as seen by the CAA Airworthiness Division staff in a review of potentially serious failures in the years 1981-3 in Appendix V; nine types of helicopters were involved. We have been able to draw some simple general conclusions which we can record now, and will discuss in more detail in later paragraphs.

(i) Overall engine reliability on helicopters is not particularly good, (according to information obtained during a visit to the USA) but public transport helicopters (with a few exceptions) have twin engines which give a measure of protection.

(ii) The latest helicopter designs, using composite rotor structures appear to have better fatigue properties than their predecessors.

(iii) The principal source of critical failure is in the rotor-transmission area, namely in the rotating machinery.

(iv) The typical failure in the rotating machinery is due to defective detail design, not discovered during development testing.

(v) There is clear evidence of the inadequacies of the forecast lives of components, both structural and dynamic (i.e. rotating machinery) specified by manufacturers, pointing inter alia to inadequate assumptions on assumed flight operational duty "spectra" and the applied loads themselves.

(vi) Vibration levels are sufficiently high to cause unforeseen structural problems

While clearly there are variations in all these matters between one helicopter design and another, we believe they can be applied to helicopters of all makes on both sides of the Atlantic.

7. Engineering Review : Today and Tomorrow

7.1 Powerplant

All but the smallest machines now use turbines, and usually two (or occasionally more). Desirable practice is to be able to hover out of ground effect following engine failure at reasonable all-up-weight, and to be able to continue flight, in the multi-engine case, or to make an autorotative landing in the single engine case.

Data we have obtained show that although present engines (as installed) have a significant failure rate, they do not often cause fatal accidents.

In practice engines chosen to power helicopters are likely to have been developed for conventional aircraft applications, or for some military duty. In practical use in twin engine applications they are likely to spend most of their cruising life at rather higher power levels than they might if used in a normal propeller aircraft; the frequency of full power application may be less. Indeed it is now the practice to consider power schedules specifically for helicopter use.

Although the Panel consulted the main engine manufacturers for helicopters in the UK and USA, it did not determine any special area which it thought required attention. We would point out that solutions involving more than two engines, due to the additional mechanical complexity involved, must require additional development testing of the whole powerplant transmission system.

Some of the Panel feel, however, that more consideration might be given to dividing up the total reduction gearing between the engine and rotorhead (possibly an overall ratio of 100 to 1), having part in the engine proper (as is the practice in a propeller turbine and indeed in some of the small helicopter turbines) and the remainder in the special gear box. This would share out the development responsibility, simplify the main gear box and probably facilitate the application of health monitoring. One manufacturer in fact already has adopted this policy on a large machine.

7.2 Helicopter Structures

We have not concerned ourselves with the conceptual design of helicopters although we have noted that the likely types which will carry passengers in the future will have single rotors with engines above the passengers, or twin rotors with a fuselage between. We have not thought it likely that jet driven rotors, or tilt wing "convertible" machines will enter civil transport service for some time.

We have noted that all helicopter manufacturers are interested in the use of composite materials for their future structures. The replacement of much of the light alloy used at present with composites seems inevitable and for general structural use we believe that the problems encountered will be the same as for fixed wing structures. The ARB reviewed this new technique in 1981 and noted problems which apply equally to helicopters, namely:

(a) the lack of National or International material specifications;

(b) the lack of ductile failure, or energy absorption, which affects the crash case;

(c) loss of properties with moisture absorption and temperature;

(d) non-conductivity in the event of lightning strike;

(e) problems of quality control of the manufacturing process;

(f) different local damage repair techniques.

All these matters are being dealt with and the Panel sees no particular problems associated with helicopters (we refer to crashworthiness below).

We have been surprised to note the number of incidents which have been caused by the failure of subsidiary structures of helicopters These seem to have been aggravated by the severe vibration to which the whole machine is subjected, as discussed in para. 7.5 below. More attention to this type of potential failure seems to be needed.

7.3 Fatigue

A significant amount of the unreliability and failure of helicopters can be attributed to fatigue. Fatigue affecting helicopters can be considered in two major categories which are mainly distinguished by the frequency of load cycles which dominate the accumulation of fatigue damage. One category involves alternating loads of a relatively "high frequency" of occurrence (several times a second) and mainly affects such items as rotor blades, rotorhead, controls, transmission, and engine mountings. The other major class involves significant fatigue loads at a much "lower" frequency of occurrence (several times an hour) and mainly affects such items as landing gear and fixed aerodynamic surfaces. This lower frequency fatigue is the type experienced by fixed wing aircraft. Here great strides have been made in aircraft design by the use of multiple load paths, crack stoppers and so on, such that fatigue, when it occurs, can now be contained by ground inspection and rectification. Accidents due to fatigue of fixed wing aircraft structure are now rare due to the adoption of the failsafe or damage tolerant approach.

The "high frequency" fatigue is the more significant case for helicopters, the source of loading being the rotation of the rotors. In this case fatigue life estimates are very sensitive to changes in stress level and hence sensitive to assumptions made concerning, for example, S-N curve shape, scatter factors, loading spectrum, testing simplifications in relation to real life conditions (wear corrosion etc), and so on.

In transmission and gearbox parts, there are further complications involving the surface fatigue of gear teeth, roller bearing tracks and the like.

Here loads are transmitted by intermittent contact of mating surfaces, usually along a line, where the two contacting surfaces bend (under Hertzian loading) and eventually the surface fails locally. Debris from the surface comes off, usually slowly enough to be detectable in the oil in the lubrication system. Gear teeth and other parts of the transmission may crack from stress concentrations or local material defects, this type of failure being more akin to conventional fatigue, but usually more difficult to inspect or guard against by "crack stopping". We stress these differences to point out that if "damage tolerant" techniques as used in fixed wing aircraft structural design can and should be used in future helicopters, then only the development of "health" or condition monitoring seems to offer much hope for major improvement in gearbox and transmission design.

The rotor and control systems may well offer scope not only for redundant structural design but some form of health monitoring as well, to signal the presence of cracks or other defects. We have seen interesting developments during our visits.

Adoption of the fail-safe or damage tolerant approach is not as easily achieved in helicopter components subject to high frequency loading as it has been in fixed wing transport aircraft. Primarily this is because the components are small and complex and because the high frequency loading produces rapid damage growth rates with the consequent need for more complex and frequent inspections than is usual in the fixed wing approach.

7.4 Helicopter Usage

One of the critical factors in the determination of safe structures or mechanisms in helicopters is the validity of the assumptions made to determine the safe-life of a particular component or assembly. Some of these assumptions are concerned with the establishment of suitable fatigue tests and the interpretation of fatigue test results; others are concerned with the expected operational duty of the helicopter.

It has been argued that environmental variations, especially corrosion contribute to this disparity. We do not readily accept this: corrosion should be eliminated by good design and recommended maintenance, and if it cannot be it should be taken into account during fatigue testing. It may also be true that wear of mechanical components affects load distribution and again should be taken into account.

We have been told that operators regularly exceed the flight limitations imposed on helicopters. On the other hand this has been strongly denied. We do not know what the truth is, but point out to pilots and operators that exceeding limitations may have a serious effect on the achieved fatigue lives of their equipment. We have noted with interest the development of "usage monitors" - see paragraph 8.5.

Our Panel has noted major errors in fatigue life forecasting on new machines entering service in Britain (a forecast life of 2400 hours having to be reduced to 1000, 1200 to 600, 4000 to 1500: these are recent examples). In view of the sensitivity of fatigue life to change in load, we have concluded that there is a wide disparity between the assumed operational duty used by the helicopter makers and what in practice operators achieve in practical operations.

It follows that manufacturers should specify more realistic operational spectra in conjunction with customers for their helicopters, and should publish a variety of acceptable equivalent versions. It became apparent during our deliberations that there was a lack of knowledge on the achieved loading, power levels and so on, in day-today operational use, and that data should be collected by flight recording in routine operations. Indeed there is no requirement for crash recorders on helicopters, although voice recorders are becoming mandatory for larger helicopters.

We have discussed the need for a Research Programme of flight recording with the Chief Scientist at the CAA, paralleling the existing Civil Aircraft Airworthiness Data Recording Programme (CAADRP), and are pleased to record that he has accepted the need for a Helicopter equivalent and has taken steps to initiate it.

Thus we can make two formal Recommendations:

RECOMMENDATION 2. More attention should be paid by helicopter manufacturers, in cooperation with customers for their machines, to the realism of their fatigue test programmes on which component lives are determined, in relation to the actual usage to be made of the machine by the customer; and conversely the customer should satisfy himself in conjunction with the manufacturer when changing the use of a machine that the new use is still within the forecast flight profiles both in terms of severity and frequency.

RECOMMENDATION 3. A research programme should be established seeking to obtain in-flight recorded data of actual loadings and duty cycles achieved by realistic helicopter operations, and analyses should be published.

7.5 Vibration

To the modern airline passenger used to the smooth, quiet vibration-free flight "above the weather" of the modern transport aircraft, flight in some of the current operational helicopters may come as a shock, even becoming unpleasant if of any duration. Older passengers will be reminded of flights in DC3s, DC4s or even Argonauts!

We ourselves noted during North Sea flights that the passengers wore ear muffs, and that the relatively high vibration levels were momentarily extremely severe during a transition to landing. We can express the opinion that these levels will have to be much better if the helicopter is to compete successfully with conventional short range aircraft for local transport. Furthermore they must have some effect on today's crews although we did not explore this area.

It is clear that the present high levels of vibration have a more or less serious effect on instruments and equipment on board helicopters and are a major source of fatigue damage to structures and mechanical components such as primary control systems.

Helicopter vibration comes mainly from the aerodynamic forces on the rotor blades as they pass through the air and are pitch-cycled. There may be some centrifugal force unbalance also. Noise is acoustically generated by the blades and as they pass the fuselage, and higher pitched noise comes from the many gears in the gearbox and transmission.

The several manufacturers we visited were working on the understanding of the sources of vibration and reported much improvement in the latest designs, with better aerofoil shapes, damping systems, and perhaps as a result of the introduction of "elastomeric" (i.e. rubber or rubber-like) bearings in the rotor head.

We were interested to note research work on the development of 'active' control systems for the rotor, using feedback from measured accelerations to control blade motion thereby cancelling out vibration at source. We have been told that results of flight testing of such a system by the Hughes Company under a US government funded programme has demonstrated dramatic improvements.

One manufacturer has achieved significant improvement in vibration levels by "passive" methods involving the elastic mounting of the gearbox and rotor system, while another expressed some concern at the possible effect on fatigue loading of "active" systems. Continued research should clearly be encouraged.

Thus while we are not able to make any formal recommendation we must stress the importance of finding means of reducing vibration levels, not only to eliminate or reduce a serious source of fatigue failure, but to improve the quality of crew and passenger comfort.

7.6 Rotor Head and Blades

It is clear that the most critical element of a helicopter and the one most vital to safety is the rotor assembly. Traditional designs derived from the original Cierva-Sikorsky conceptions contain pluralities of pivots and bearings to give the blades the necessary 3 or 4 axis freedom and to enable the blade pitch to vary cyclically as it rotates. That so relatively complex mechanisms have achieved the high degree of reliability that they have is a tribute to the various manufacturers.

Failures do occur from components with residual design defects (usually in the early life of a new type), quality control lapses, and occasionally maintenance errors. The Panel was surprised to examine a crashed helicopter where the rotor head was attached to the rotor main shaft by a single bolt, which had failed after corrosion. The failure was formally attributed to faulty maintenance. The Panel sitting in 1983 would add faulty design but has had to note that the practice of using a single bolt or nut to attach the rotor is widespread on small machines.

It seems to the Panel that more effort should be made in the conceptual design stage to evolving rotor head and gearbox layouts with some degree of inherent safety, however relative. For example, location of the vertical thrust bearing mechanism at the top of the system might retain the rotor after failure of the gear train, while location lower down might not. In any event the study of all conceivable modes of failure and their consequences must be part of the conscious philosophy, rather than reliance on the perfection of design and manufacture.

We noted that all the helicopter makers visited were developing improved rotor head designs eliminating many of the mechanical bearings required by blade hinges, in favour of "elastomeric" bearings, which according to at least one manufacturer are outstandingly reliable. Rotor head structures were also being widely developed using composite materials, which by the nature of the methods used for the fabrication of parts in the material, could be made multi-path and damage tolerant.

The Panel welcomed these developments subject to the general qualification already made about the need for caution on the use and manufacturing control of these new materials.

Similar developments have already taken place in the construction of the blades themselves, where metal blades have been replaced by blades built up from a variety of composites, offering, apart from better aerodynamic characteristics, the prospect of improved fatigue life, slower damage growth and better crack stopping or signalling of local failure. Some ingenious use of multiple fibres is offering better blade root construction where stiffness in bending can be combined with low stiffness in torsion, thus eliminating bearings.

Several constructions noted made use of dampers and all had hydraulic servo control for pitch change. We were not impressed with the degree of redundancy achieved. One crashed machine of an early design that we examined had failed because a small threaded end of a servo valve (about 4 mm diameter) had broken, probably due to a lock nut being over tightened.

We are certain that helicopter design requirements should be so framed as to eliminate such weakness and refer to this again later.

Since the deicing of helicopters is a major operational requirement for the future we were pleased to note that the incorporation of electrical deicing mats into the modern composite blade did not present much of a problem to the various makers we visited, although no doubt complicating the generation and distribution of power.

7.7 <u>Gear box and Transmission</u>

The most complex element of a helicopter, after perhaps the engine, is the transmission gearbox, taking the drive at high speed from one, two or more engines generally in a horizontal plane, and gearing it down by 80 or 100 to 1, or so, to a single vertical shaft carrying the rotorhead, with another drive going rearward to a tail rotor (or another rotorhead system), the engines having free wheels, and accessory drives being taken off for generators and oil pumps.

These gearboxes are remarkable examples of the art of the mechanical engineer. Although simplicity is a good starting point in the conceptual stage, complexity is inevitable, and it is not surprising that each designer has found his own solutions. The panel has seen spur gear trains, epicyclics, bevels; it has seen normal straight teeth, 'conformal' tooth profiles; it has seen ball bearings, rollers, tapered rollers, shafts with separate ball races and shafts with rollers running direct on them; we have seen aluminium and magnesium alloy cases. The only common element noted was in the gear material, a traditional low carbon nickel-chrome case hardening steel, either carburised or nitrided, and invariably made of high purity vacuum melted stock.

Notwithstanding the exceptional facilities for gear production we were shown, and the great attention to quality control being paid* we are bound to record that in our view it will never be possible to eliminate completely the possibility of failure of some part of so complex a mechanism in service, between specified inspection or overhaul periods.

* We refer to one aspect of production in paragraph 7.10.

Although minor surface damage to a gear or bearing is unlikely to be instantly catastrophic, and should be detectable, and although gearboxes are tested to run for a period such as 30 minutes with the oil supply failed, the possibility of a major failure within the box is ever present.

Since with present knowledge a main rotor cannot be duplicated although a tail rotor gearbox might (conceivably a helicopter may survive the failure of the latter) we now come up against the fundamental difference between normal aircraft and rotorcraft - the inability to guard against a possible defect by duplication.

The Panel believes that, while gearbox development and testing should be as stringent as practicable, other means must be introduced to monitor the condition or "health" of the gearbox, preferably in flight. Elementary condition monitoring is already practiced (e.g. oil chip detectors), but much more attention should be paid to this. We make our detail recommendations on this subject later in para. 8.5.

There have been failures of transmission systems taking the drive to the tail rotor, or coupling twin rotor heads. We believe it may be possible to achieve a degree of redundancy here, or at any rate 'damage tolerance'. On the other hand it may be simpler to have some other method of cancelling main rotor torque to use in an emergency (bleed gas jet, rudder surface......)

7.8 Development Testing

The Panel has been interested to note the relatively different scale of development testing as practiced by engine and helicopter makers.

A new jet engine benefits from substantial funding, often on a military budget, and may use 6 or 8 development engines, 5000 hours or more bench running, followed by flight testing and some form of route proving or endurance flight programme. It has an official type endurance test of 150 hours to obtain formal military or commercial certification.

The formal requirement for approval of a helicopter engine and transmission system is for an endurance test of some 200 hours, plus additional fatigue testing including 140% over torque testing of gears specified by the CAA (and now adopted by a least one U.S. manufacturer as standard.)

Practice in the U.S.A. differs from that in Britain in that US manufacturers seek the minimum of formally demanded FAA certification requirement, but have their own and often relatively high standard as an in-house requirement (this aspect is sometimes overlooked by European industry seeking FAA approval at the minimum level). In Britain there is less divergence between CAA requirements and manufacturers' in-house standards.

Members of the Panel discussed testing practice and requirements with the various firms visited. We do not propose that formal requirements should specify much if any additional testing. We do wish to state that good practice for the development of a new engine, gearbox and transmission system should include, in addition to hundreds of hours of element (component) testing a great deal of full scale testing of the entire system with fully representative loading. This would be the less if much of the design were of a proven, understood type; it would be the more if the system were novel.

An example of the latter seems to us to be a new helicopter design using 3 engines coupled to a single gear box, and no doubt with 40-50% more mechanical elements within it than previous 2-engine practice.

We also draw attention to the well-known (to development engineers) weakness of simple rig testing. Most development programmes suffer from the small population of samples tested, due to time and financial limitations. International cooperative programmes in engines and airframes have benefited from a degree of duplication, with two teams tackling problems.

We do not wish to attempt to specify numbers of hours which should go into gearbox and transmission testing, since it is the quality as well as the quantity which is important. We did note practice which we felt to be good, stated to be 500 hours bench running, 1500 hours flight testing plus special attention to the early service life of the type (see para. 7.9).

7.9 <u>Service Development and Product Support</u>

It is a fact of engineering life that no matter how great the effort put into developing any complex product such as an aeroplane or helicopter not all residual problems or defects will have been eliminated when it first enters service. The proper procedure has been and should be for the manufacturers and the initial operators to cooperate fully to eliminate early defects.

This is often easier to say than to achieve. To remedy defects means change, which takes time and money and requires replacement or new parts. But in the case of helicopters safety may well be prejudiced, especially if the problem areas are in the rotor or transmission system.

The Panel has not found that the sort of cooperation achieved by airlines when introducing new civil aeroplanes or engines is much in evidence in the helicopter field. We would wish to see frank interchange of problems and solutions between helicopter operators using the same type. We do not feel that the Mandatory Occurrence Report (MOR) System specified by CAA is the right method to rely on, during the early months of the service life of a new type. A more intimate and direct system is needed. We hope to see more evidence of this in future.

We have been impressed with the increasingly general practice of monitoring the "fleet leading" machines, getting back for examination the first components such as gearboxes, on completion of say 500 hours, for detail examination. We believe that this sort of approach can do much to extend knowledge derived from development testing.

Whether the CAA should have an active role in such continued development may be open to question. In so far as any determined effort to improve reliability must contribute to the safety of helicopters we believe a strong case can be made. It may be considered better to rely on the good sense of a manufacturer together with an initial operator to agree sensible technical, and commercial arrangements, with the CAA kept informed. Where, as is increasingly likely, a machine is being developed for a mixed military-civil role, it is clearly desirable for the CAA to collaborate with the Military Authorities in evolving a suitable system.

We do wish, however, to make the following recommendation:

RECOMMENDATION 4. We recommend that before a new type of helicopter is introduced on to the British Register the manufacturer and operator should evolve a system, in conjunction with the CAA, the better to review and take action upon service difficulties affecting airworthiness; where more than one operator is involved on a new type, the system should allow for cross feeding of knowledge and experience between operators.

7.10 Quality Control

The Panel was impressed, during the various visits it made to manufacturers, with the efforts being made to ensure safety by quality control procedures during manufacture. It has been said, with undoubted truth, that quality starts on the drawing board. It is equally true that the most important factor of all is the engendering throughout an organisation of a spirit or atmosphere that quality is vital and that everything must be 'done right'. Although we found this spirit everywhere we went, there is still scope for faults or errors to be made by the humans who administer procedures. Creating additional or new procedures may do more harm than good. Since engine companies have been in the high quality precision mechanical engineering business for longer than the helicopter firms, we asked a senior engineer from the Airworthiness Division of the CAA, Mr. G. Gunstone, recently retired from being in charge of the Powerplant Section, to consider whether the engine industry has anything to teach the helicopter world in the practices or procedures of Quality control.

He has concluded that there is a strong case for introducing a category of "VITAL" component, where critical parts of the design cannot be made "damage tolerant". The quality control procedures for such parts would be handled with the utmost seriousness.

The Panel believes that it is important for the CAA to publish a manual of recommended practice along the lines of the excellent preliminary proposals from Mr Gunstone which it has seen, to assist all concerned in the manufacture, operation, maintenance and overhaul of helicopters to establish and maintain the quality of "VITAL" components. Thus it makes a Recommendation as follows:

RECOMMENDATION 5. The CAA should prepare and publish a Guide to the Establishment and Maintenance of Quality Control of Helicopters.

In view of the vital importance of gearboxes and related parts the Panel believes that where a sub-contractor is used for their manufacture this sub-contractor should himself be approved and regularly monitored and his procedures audited. It may be impractical for the CAA to do this themselves, especially overseas, but in this case the responsibility should be placed on the helicopter manufacturer and the CAA kept fully informed on the results of surveillance. Thus we make a further Recommendation:

RECOMMENDATION 6. The CAA should develop a procedure for the approval by the helicopter manufacturer of manufacturers of gearboxes and other vital assemblies where these are not produced by the main manufacturer themselves.

7.11 Maintenance and Inspection

An analysis of the detailed causes of reportable accidents to helicopters on the British Register over the period 1976-83 showed that 29% of accidents from airworthiness causes were due to "small but significant parts". Typical examples are:-

> 40 cms of leading edge tape missing from one main rotor blade tip (the aircraft was destroyed)
> incorrect location of O-ring in rotor damper (the aircraft suffered substantial damage).

Though similar examples are to be found in accidents to fixed wing aircraft the higher proportion of airworthiness accidents on helicopters suggests that they are more significant in the latter. Failures of this sort are difficult to deal with. However, they are worth noting because they highlight the need for a high standard of maintenance and inspection to ensure that no important detail is missed. The Panel observes that although the maintenance instructions are the essential basis enabling this to be achieved, and must be reviewed regularly in the light of experience, their effectiveness must ultimately depend on the capability and integrity of the organisations and engineers concerned.

8. Future Progress

The Panel has noted, or its attention has been drawn to, a number of areas where progress is being or will be made, leading eventually to Requirements. These have been discussed in Committee and the Panel's views are given below.

8.1 Operational Matters

(a) De-icing. Britain has cleared a small number of helicopters for flight in limited icing conditions, having regard to the lower altitude environment in which they operate, and their ability in certain cases to reduce altitude to avoid ice. The FAA told the Panel in November 1983 that they expected to clear one type (the Aerospatiale

Puma) in early 1984. We note too that the RAF is sponsoring a major programme for the Vertol CH47 (Chinook) to be carried out in Canada.

To obtain an unrestricted clearance would be a lengthy and expensive procedure, if only because of the difficulty in finding the right icing test conditions. Limited clearance of particular types against particular operations have come about mainly because operations, especially in the North Sea, can be greatly hampered if operations in forecast icing conditions are prohibited.

Although it has been demonstrated for a number of types that safe flight is possible in light or moderate icing conditions with only limited ice protection devices, there is a need for caution in the granting and use of restricted clearances. The icing environment is not wholly predictable, and consequently a helicopter cleared to operate only in light or moderate icing conditions might encounter icing conditions more severe than those in which it had been demonstrated that the type could safely operate.

In order to minimise the resultant risk it is necessary to ensure that it will always be possible to escape into warmer air, so that any excessive ice accretion is rapidly removed and recovery of full control and normal performance is assured. CAA have therefore required that a band of positive temperature air at least 500 feet in depth should always be available below the helicopter's flight path, into which the aircraft can safely descend if icing conditions more severe than those encompassed in its clearance are encountered.

Even with this protection a degree of hazard, which it is difficult to quantify, remains. If the aircraft is some way above freezing level it will not be able to exit from the icing conditions immediately, but may have to descend a few thousand feet while still suffering further ice accretion, possibly at a high rate. To guard against this hazard the helicopter is normally required to be shown to be capable of withstanding for a short period conditions more severe than those in which it is approved for continuous operation.

A second potential problem is that the need to descend may conflict with the need to maintain air traffic separation, which may present operational problems.

The requirement for a 500 foot band of positive temperature air has not been limiting on North Sea over-water operations because the freezing level over the North Sea is rarely below 500 feet. Over land, however, the requirement can be much more restrictive, both because the minimum safe altitude under instrument meteorological conditions may be several hundred feet above the surface, and because air temperatures are frequently below zero at ground level.

Operators have indicated that application of the requirement to terminal area operations has serious adverse operational consequences (especially on off-shore operations from the Scottish mainland, and the Gatwick-Heathrow link). Nevertheless, the CAA position is that the requirement is reasonable, and should be applied as a Flight Manual limitation; the Panel supports this view, certainly in the light of present knowledge.

We know that there is good collaboration between the CAA and the FAA on icing matters and welcome it. We are bound to point out, however, that progress will be slow, and that it may be some years before an adequate well defined requirement covering full icing clearance becomes available.

Close collaboration between Civil and Military Authorities is clearly highly relevant and important.

(b) Instrument Flight (I.F.R.). The fuller exploitation of passenger carrying helicopter operations will demand all-weather IFR flight. The Panel believes that the necessary equipment is available (see paragraph 8.6) and that helicopters can be provided with the appropriate fit if required.

Since all-weather flying may involve more severe conditions than hitherto, we believe that structural gust requirements should be reviewed.

We did note that the FAA were developing a runway lighting system suitable for small city centre heliports.

8.2 "Damage Tolerance"

"Damage Tolerance" in the conventional civil aircraft structural context is a term used to describe the current state of the art in the design and certification of fail-safe structures.

The concept of damage tolerance for helicopters was introduced by the FAA in a 1983 proposal at the same time as the CAA was making a recommendation that the introduction of damage tolerance requirements for helicopters should be a long term objective (see paragraph 9(e)). The FAA proposal is expected to be introduced in 1985 as a requirement. It seeks to make the designer consciously study "what happens if" some part of the structure or system fails, encouraging duplicate load paths, redundancy and so on.

While civil fixed wing aircraft designers have long (since about 1955) adopted damage tolerance or fail-safe principles (multiple load path redundant structures, for example) or the multiplexing of navigation or servo systems, it has not been so easy for the helicopter designer to accept this philosophy, because he has difficulty in seeing how to do it. Neither has there been any regulatory pressure for the helicopter industry to move in this direction.

Noting that in the past some limited damage tolerance features have been adopted, the Panel feels that there is much scope for expanding the application of these principles; thus the Panel wholeheartedly supports the FAA and CAA proposals, although expecting that some re-writing of the present FAA paper (which seems to be written unintentionally as referring only to structural elements) will either take place or needs to be done and recommends joint action in this area.

8.3 Crashworthiness

It seems generally agreed that helicopters when they do crash cause avoidable injury (often fatality) to the passengers and crew. Seat integrity is inadequate and in too many cases fuel tanks disintegrate and cause major fires.

There is a major programme for military helicopters in U.S.A. which involves considerable increase in structural strength and energy absorption ability but we do not feel that the weight penalty this involves would be justified for civil transport. We have seen some ingenious and low weight devices for absorbing energy in seats (by elastic deformation of steel rods), but we appreciate that items cannot be considered in isolation. We believe that there is a case for raising the energy absorption capability of the landing gear (and ensuring that it entrains no consequential harm when it fails), designing and then testing the structure of new helicopters to optimum energy absorption capability and increasing the attachment strength and then absorption capability of seats; our American friends refer to the need to 'delethalise' seats, which we support. We have been told that major benefit could come from adequate seat belt restraint, using diagonal straps as on a car (but anchored to the seat); we can readily believe this but cannot comment on the weight penalty, which might be severe. There must be scope for ingenuity here.

We can support however without qualification proposals to ensure that fuel tanks are better protected (by improved linings) against rupture on crashing, and that fuel piping systems should have self-sealing couplings to prevent pipe leakage.

We can thus make two Recommendations:-

RECOMMENDATION 7. A study should be initiated forthwith to identify suitable requirements for an improved standard of crashworthiness of the structure as a whole, landing gear, seats and possible restraint systems, having regard to possible military-civil cooperation in this area.

RECOMMENDATION 8. Immediate steps should be taken to require better standards of crashworthiness of fuel tanks and fuel systems.

We must add that in parallel with structural improvements is the need to ensure that exits are adequate and themselves 'crashworthy'.

8.4 Ditching. Ditching is really part of Crashworthiness but better considered as a separate case, and one of particular concern to the British helicopter industry operating as it does for long distances near the sea. We believe it will be a long time before extensive scheduled passenger services are flown for long periods over water. Those who fly out to North Sea platforms wear sophisticated survival suits and are instructed in their use; we cannot believe this would be acceptable to the normal fare-paying passengers.

The frequency of forced landings (and hence in overwater operations of ditching) is such that a high probability of survival of all occupants is essential. To achieve this, the helicopter must have adequate buoyancy, stability, practicable means of escape and effective liferaft equipment.

Buoyancy needs to be assured in order to provide the pilot with ditching as an acceptable option, and there are strong arguments in favour of deployment of flotation bags before contact with the water. Reserve buoyancy may be desirable in the event of survivable damage. The need for stability is emphasised by the very limited practicability of escape from a capsized helicopter. The conditions on which the stability of the helicopter should be demonstrated must take account of realistic wind speeds accompanying severe sea states. Special consideration needs to be given to conditions in the very inhospitable areas such as the Northern North Sea.

There are a number of aspects of liferaft deployment and operation that need review. Draft Requirement papers are in an advanced stage and we would advocate early publication and application.

Thus we make the following recommendations:-

RECOMMENDATION 9. We propose that draft requirements covering Ditching be published at an early date to encourage technical consideration.

RECOMMENDATION 10. We propose that resolution of the problems of stability of a ditched helicopter be urgently pursued.

8.5 Condition Monitoring

Condition or Health Monitoring is not a new technique. It has been practised for many years for jet engine maintenance, where "on condition" overhaul has replaced engine removal after specified periods (time between overhaul : T.B.O.). Indeed a Report on Condition Monitoring of machines, published by the Dept. of Industry in 1979*, outlined the significance of the procedure to general industry, which had been under consideration by a DoI committee since 1970.

As this report states "Condition monitoring is concerned with extracting information from machines to indicate their condition, and to enable them to be operated and maintained with safety and economy".

(* A Guide to the Condition Monitoring of Machinery, Michael Neale and Associates, H.M. Stationery Office 1979; this followed an earlier report by these consultants in 1975.)

Practice in the engine field however allows for a mixture of pilot-displayed monitors (warning lights indicating excess magnetic debris from metallic particles generated improperly from gears or bearings; unusual vibration "noises") and ground detected abnormalities (unusual metallic particles in oil samples, or visual examination of internal condition by "Boroscopes"). All this is predicated by a philosophy which accepts that engine failure will not be catastrophic (as the remaining engines, if one fails in flight will enable flight to continue), but that the total system cost will increase if an engine is removed for overhaul before it is necessary.

What the Panel would wish to propose is a philosophy based on the argument that where full redundancy is not possible in the design of helicopters warning of likely failure (at some reasonable period ahead in time, maybe only an hour or two) could provide the equivalent overall safety level.

Because we viewed this possibility as important we sought the help of Rolls Royce who are already skilled in these matters, and they kindly made available to us a senior engineer Mr. C. Elliott whose report on Condition Monitoring was considered in detail by the Committee and is available to those concerned with developments in this area. We are grateful for this assistance.

In general terms we wish to see the potential techniques of Condition Monitoring exploited more fully. We are well aware that a monitoring system which is not reliable may be worse than no system, since spurious warnings will lead to warnings being ignored. But we believe that the long term potential of the modern reliable micro-electronics and the parallel development of micro-transducers will lead to devices whose reliability and performance can bring great benefit.

We make the following brief comments on the various known systems:-

(a) chip detectors: some helicopters already have warning lights on their central warning (annunciator) panels illuminated by excessive chip collections on magnetic plugs in gearboxes. The information is qualitative and plugs are often removed for examination for quantitative assessment of debris. Proper location of plugs requires demonstration during development. Newer developments allow for some degree of discrimination on particle size, as between small and large debris.

(b) vibration monitoring, the principles of which are well established is at a very early stage but offers much hope for the future. We would hope to see airborne equipment with computorised analysis to simplify the display of information to the crew.

(c) thermal detection or imaging in flight might be useful. It is already in use during testing.

(d) oil sampling by spectrographic or similar methods to detect metallic particles is regularly used by maintenance crews on the ground. Samples have to be sent to laboratories for analyses. We see no reason why special portable equipment to detect a limited number of materials (perhaps only iron) should not be developed for airline use. It is not inconceivable that continuous airborne sampling may be evolved.

(e) telemetry (of information between aircraft and a ground station) is already being used by airlines. It may have potential on helicopters to remove some responsibility for monitoring critical elements from the pilot to a ground specialist.

(f) A newer development is a "Usage Monitor" to be carried in the helicopter and to monitor, via an airborne computer, actual engine, rotor and transmission parameters, enabling assumed use to be compared with reality. This must represent a major step forward.

We wish to see research and development in these areas encouraged; it is a fruitful field for engineering ingenuity and research workers in universities and industry, and while equally applicable in the military and civil helicopter field, has applications throughout general industry.

Thus we make the following Recommendations:-

RECOMMENDATION 11. The CAA should set up a working party between experts in the Airworthiness Division, Ministry of Defence and selected specialists from universities and industry to draw up proposals or requirements for parameters to be measured and for new or improved condition monitoring devices or systems, to be widely publicised.

RECOMMENDATION 12. The CAA should draw the attention of the Science and Engineering Research Council to the benefits to be obtained by industry as a whole from supporting work in condition monitoring.

RECOMMENDATION 13. The CAA should draw the attention of a Learned Society (for example the Royal Aeronautical Society) to the need to stimulate developments in condition monitoring by the promotion of discussion or conferences.

8.6 Navigation and Avionics

The rapid pace of development in airborne electronics for fixed wing aircraft, especially in flight deck displays is reflected in parallel developments for helicopters. The Committee has had the benefit of considerations by a few of its members with specialised knowledge in this field and their advice can be summarised as follows:-

(a) Automatic equipment, such as autostabilisers, is being developed to improve the operation and handling of helicopters. This emphasises the need for joint military and civil development and the uses of the best civil aircraft safety disciplines to guard against failure.

(b) Helicopters should have good stability, if necessary using automatic devices; these can be used to facilitate emergency auto rotation landings.

(c) Total loss of electric power could well be very serious indeed; the generating systems used in helicopters need to be very secure.

(d) Weather radar is widely used on helicopters for mapping, especially for terminal guidance. This should be taken into account in the development of the equipment.

(e) Radio altimeters seem essential, but are not formally required. They should be of high integrity.

It is suggested that, to assist the pilot, they should be used to signal the optimum transition point in an emergency auto-rotation landing.

(f) Manometric airspeed instruments are often inaccurate below 50 knots, due mainly to position errors.

(g) Ground proximity warning systems (GPWS) suitable for helicopters seem highly desirable and should be developed and used.

Since the key to the development in all these areas must be in joint developments as between military and civil requirements the committee does not make any further recommendation; it would wish to see progress in this area to result from the recommendation relating to Military - Civil collaboration given in para. 10.

9. <u>Requirements</u>

The staff concerned with helicopter work within the Airworthiness Division though few in number (although recently strengthened) have been working for some time on a number of new or improved requirements.

While in the long term it is expected that the several European Certification authorities will harmonize their helicopter regulations into a joint Airworthiness format (JAR) the Panel feels that the British work should continue with increased vigour; much of it may find favour in a JAR context, all of it will help to form British opinion as to good practice.

Many of the items are already being discussed with the European Authorities and the FAA, giving the prospect of truly international agreement.

While the Panel does not wish to comment on the detail of the various draft proposals or papers, it can make the following broad comments in support.

(a) G780 - Categories. Separation of existing code into large and small helicopters, coming into line with the FAA and JAR. The dividing line is at 6000 lb, with a single piston engine, the larger machines including any with turbines. Different levels of engineering integrity are considered and operational limitations depending on the category are proposed.

(b) G610 - De-icing. This has been in draft form for some time and the Panel proposes that efforts should be made to bring it into line with what the FAA appear to be doing, as outlined in para. 8.1(a).

(c) G778 Rotor and Transmission Systems. This is an important paper outlining clearly the inherent problems with these systems and requiring thorough consideration, assessment and failure analysis.

(d) (G811 in preparation) Health Monitoring. Requirements to encourage the development and use of known techniques.

(e) (G813 in preparation) Damage Tolerance Requirements. Parallel paper to that proposed by the FAA.

(f) (G814 in preparation) Fatigue Requirements. Up-to-date thinking on required fatigue testing and documentation, including consideration of worn or corroded parts.

The Panel has noted that staff action is proposed on a number of other subjects, including:

(a) Gust loading (particularly for all-weather operations)
(b) Bird impact (the Panel noted differences between FAR and BCAR)
(c) Flutter substantiation including auxiliary aerodynamic surfaces
(d) Flight testing of helicopters
(e) Integrity of power controls
(f) New liferaft requirements.

The Panel however wishes to make one comment which it considers of particular importance. There is an opportunity today, given the willingness of the FAA to collaborate actively with Europe, to make significant progress towards better International Helicopter Requirements. To exploit this to the full requires effort and enthusiasm from an adequate staff. We are well aware of the problems which a diminished, indeed inadequate, staff level presents and are thus led to make the following recommendation:-

RECOMMENDATION 14. The CAA should make arrangements for financial provision for sufficient increase in staff levels concerned with helicopters within the Airworthiness Division to enable the various new Requirements to be prepared and processed expeditiously; and consideration should be given to some of the associated research work being carried out on a consultant basis, for example using the skills of the College of Aeronautics or like bodies.

10. Military Collaboration

Much of the stimulus to the development of the helicopter arose from military interest in its potential as soon as Sikorsky demonstrated a practical machine in 1940. The exploitation since by the world's Navies, Armies and Air Forces has been remarkable. Vietnam and the Falklands Islands are two examples. Hundreds of lives have been saved around Britain's shores by Air Sea Rescue helicopters, far more indeed than have been lost in helicopter accidents.

Civil helicopters have grown out of these military developments, although we note a recent tendency in that field to make helicopters more resistant to weapon damage which is more likely to bring indirect than direct benefit to the passenger carrying machines.

The Panel believes that there might be more direct collaboration in Britain, which has a single helicopter manufacturer, between the military and the civil requirements makers, and indeed the research workers in this field, a role once performed by the defunct Aeronautical Research Council.

The Panel had an opportunity of discussing existing collaboration between the MOD and the CAA on helicopter safety and requirement matters. It noted that there was in fact much contact, but that most took place through the main British manufacturer. In the case of a new machine recently contracted for, considerable effort had been made to harmonise military and civil requirements.

There is, however, no formal contact or procedure at a policy level where new needs can be discussed and views exchanged. The Panel feels that there is a balance to be drawn between commonsense consideration of likely benefit by discussion of the needs of the two types of user and the interference in the autonomy of those responsible for defence development and expenditure. Thus we make the following recommendation:

RECOMMENDATION 15. The CAA should discuss with the Ministry of Defence the setting up of some sort of formal collaboration on helicopter matters. This should include consideration of development of safety requirements and the exhange of appropriate in-service information.

11. Economics

Throughout its deliberations the Panel has been aware that many of its findings and recommendations if implemented will result in increased expenditure in many areas and by the several organisations involved. They imply a need for increased investment in research, in design, in development and testing, in new equipment and in monitoring after entry into service. The Panel believes that responsible operators, and they in the ultimate have to meet the increased costs, appreciate that if helicopter operations are to develop and expand an improvement over the current standard of safety has to be demonstrated.

The operators know that unreliability and especially accidents cost money, either in lost revenue or in direct wastage. Thus within limits they are no doubt prepared to make their contribution.

The national attitude is not so clear-cut. Accidents and casualties are a great waste of the nation's assets. The FAA for example is now preparing cost-benefit analyses of changes, where the cost of change is compared with the cost of the potential accidents which the change may prevent, using specific money values for human life. The Panel do not suggest that such rigid procedures should be adopted in Britain but can point out that money spent on reducing accidents and saving life is money well spent; and insofar as many of the proposals involve advanced technology it can point out that the benefits may well extend beyond the helicopter sphere.

We note however that the commercial pressures on operators and manufacturers are intense and because of the international nature of the competition the improved standards, with their associated higher prices, have to be introduced on an international basis if one country is not to be placed at a commercial disadvantage. It takes time to get international agreement, but we should not allow this to deter us in the UK from starting on the research work, including operational data collection, on the framing of new requirements, on the development of new devices and the new design concepts and so on which have been proposed in our report.

12. Retrospective Action

The Panel, in stating what they believed should be done to improve helicopter safety obviously gave consideration to what it should recommend be done about existing machines which fall more or less seriously short in some or several areas to the standards proposed.

Even if considerable effort were to be made by the staff of the Airworthiness Division to prepare all the required new requirements in the next few months (which would require more specialist staff than is available), the present and desirable procedures for discussion, comment and approval of new requirements involve years rather than months. Add to this the demonstrable need to achieve International agreement and it becomes clear that three or four years at least are required before significantly improved requirements can be promulgated. And these then become applicable to helicopters designed after the date of publication!

It would be irresponsible for the Panel to propose that particular requirements should be applied to existing machines on the British Register; a great deal of time and money would be required to design, develop and apply the appropriate modifications, supposing indeed they were practicable.

Until such time as new requirements are published we strongly recommend:

(a) that drafts are made available to helicopter designers so that they may know what is coming and take anticipatory action if they will;

(b) that Operators are encouraged to consider the recommendations we make in this Report, with a view to moving in the recommended direction as far as is practicable, especially on new orders for helicopters they may be able to place.

(c) that Oil Companies and the like who sponsor helicopter operations also review what is recommended and give consideration to absorbing the costs involved. After all they will be the principal beneficiaries.

The Panel believes, as a result of the work it has done, that there are operations, especially over the North Sea, which should have at an early date a higher basic technical design and equipment standard in such areas as ditching and some aspects of crashworthiness. It suggests that the CAA discusses what might be done now, well ahead of the issue of formal Requirements, with particular operators to see what could be achieved on a short term basis to improve the immediate level of safety, having regard to the recommendations made above and in our report.

APPENDIX I

TERMS OF REFERENCE

1. To review the existing airworthiness requirements for public transport helicopters, taking into account associated operational practice.

2. To recommend in principle such changes as are considered necessary and practicable to ensure that the safety standards of these aircraft match more closely those of comparable fixed wing aircraft.

3. For the purpose of this task and after consulting the Chairman of ARB, the Committee may co-opt other persons to serve on the Committee, and may consult any other authority, organisation or individual.

4. To report to the ARB.

APPENDIX II

Members of HARP Panel

Name	Profession	Nominating Body
Dr H G Conway (Chairman)	Formerly M D Rolls Royce Ltd	Member of ARB
Captain A C Gordon	Operations Director Bristow Helicopters	Member of ARB
Mr G A Cropper	Head of Aircraft Projects Department	CAA
Captain H A Hopkins	Formerly Senior Airline Pilot, British Airways	Member of ARB
Captain R A Lister	Head of Flight Operations 1	CAA
Mr R Maxwell	Superintendent MSI	RAE
Mr D E Morris	Formerly CAA Chief Scientist	Member of ARB
Dr M Parker	Technical Director British Airways Helicopters	BHAB
Mr J E Pateman	Managing Director Marconi Avionics	Member of ARB
Mr V A B Rogers	Director Westland Helicopters Ltd.	Member of ARB
Mr P Sibley	Chief Engineer Air Hanson Engineering Ltd.	BHAB
Dr W J Strang*	Deputy Technical Director BAe	Member of ARB
Dr K G Wilkinson	Formerly Deputy Chairman British Airways	Member of ARB

* Dr Strang ceased as a member of the Panel on being appointed Chairman of the ARB in November 1983.

APPENDIX III

EUROPEAN AND AMERICAN HELICOPTER INDUSTRIES
SOME COMPARATIVE STATISTICS

	Personnel	No of Helicopters Produced in 1983	Turnover/Sales (US $)* in 1983
Aerospatiale	8000	263	2,104 M
Agusta	5600	100	294 M
Bell	6000	340	2,900 M
Boeing Vertol	4500	25	400 M+
Hughes	5800	178	571 M
MBB	2200	165	214 M
Sikorsky	12000	191	1,000 M (1982 sales)
WHL	7200	55-60	490 M
Europe	23000	583-588	3,102 M
America	28300	734	4,871 M

* Conversion rates £1 = 1.5 US $ = 12 FF = 4 DM = 2400 Lira

\+ Assumed

APPENDIX IV

COMPARATIVE STATISTICS ON HELICOPTER AND FIXED-WING ACCIDENT RATES
(Summary of study carried out by a Sub-Committee)

In order to make a reliable comparison between accident rates on different types of aircraft, the first essential is that the source data for the statistics must be consistent. Further, if accidents from airworthiness causes are to be extracted from the total reported (reportable) accidents, then the available description of each accident must be sufficiently detailed to enable this classification to be made. Whilst reasonably reliable and consistent data are usually available on accidents to aircraft on the British Register, both in terms of accident details and hours flown by the type, the number of accidents is, happily, too small to make meaningful statistical comparisons. It is therefore necessary to look world-wide, and here the best assembly of data readily available is the World Aircraft Accident Summary (WAAS). However the use of world-wide data introduces a number of problems which may be summarised as follows:-

(a) In principle the WAAS contains all reportable accidents to aircraft over 5700 kg AUW, but the definition of "reportable" and the standard of reporting vary widely so that an accident being reported in one country would remain unreported if it occurred in a different country. (For example, a Boeing 727 with passengers aboard made a wheels-up landing in a foreign country where the accident was considered not to be reportable.)

(b) The descriptions of the accidents are frequently so sparse that its classification as being due to airworthiness or other causes is largely guesswork.

(c) The only source of data on the number of hours flown by the type is the manufacturer who, even if he has the data, which is not always the case, may not always make them available.

It must also be borne in mind when comparing helicopter accident rates with those on fixed-wing aeroplanes that their operational tasks are usually very different, many helicopter operations being impossible for fixed-wings and often carried out in a hostile environment. Accepting these limitations both on the accuracy of the data available and the validity of comparisons, a number of statistical assessments have been made and summarised below:

1. For aircraft on the British Register the fatal accident rates from airworthiness causes for multi engined fixed-wing up to 30 seat capacity, and twin engined helicopters are in the ratio 2 : 10.

2. On a world-wide basis the accident rates for turbo-jets, turbo-props and large twin engined helicopters are in the ratio

   1.5 : 4 : 10 for all fatal accidents
   1 : 2 : 10 for all fatal airworthiness accidents.

3. The results of a detailed study of the total known history since entry into service of specific but typical types can be summarised as follows:-

	Accident Rates per 10^5 Hours		
	Jet transport (100 seat)	Prop Turbine Transport	Typical Helicopter
All accidents	0.4	2.0	2.0
All airworthiness accidents	0.08	0.5	1.0
Fatal airworthiness accidents	0.01	0.07	0.5

The broad general picture is clear, that when compared on a 'per hour of flight' basis the helicopters are significantly worse than fixed-wing aeroplanes. The average flight times for the aeroplanes considered were about one hour, while the average time for helicopters in North Sea operations is about 30 minutes, and if this is true for helicopter operations overall then the ratios quoted above for them would be halved when treated on a per flight basis.

4. Conclusions

From the data studied the Sub-Committee was able to draw the following conclusions:-

4.1. Helicopter accident rates, either on a per hour or per flight basis are significantly worse than those for modern jet transports, although comparable to propeller turbine transports.

4.2. The percentage of all accidents which is due to airworthiness causes is higher on helicopters than on fixed-wing aeroplanes.

4.3. The percentage of accidents from airworthiness causes which prove fatal is significantly higher on helicopters than on fixed-wing aeroplanes.

4.4. Helicopters which have had the benefit of military experience before entering civil operations have a better accident record in their early years of service than one helicopter which was launched directly into the civil field.

APPENDIX V

SIGNIFICANT EVENTS RELATED TO FATIGUE OR MECHANICAL FAILURE
(Large Transport Helicopters - CAA involvement since 1981)

This list represents incidents which have required the close attention of the Airworthiness Division staff and does not necessarily include all the incidents which occurred in the stated period.

The importance of each event is indicated qualitatively by the judgement of the surveyor concerned.

Occurrence	Accident	Potential Accident	Serious
Spindle Thread Failed	x		
Head Damper Lugs Failed			x
Spindle Lugs Failed		x	
Hub Spline Cracks		x	
Fuselage Cracks			x
Tail Boom Attachment Cracks			x
Landing Gear Leg Cracked			x
Pitch Shaft Cracked		x	
Rotor Hinge Pin Cracked		x	
Grip Failed		x	
Hub Retention Nut Cracks		x	
Pylon Mounting Cracks			x
Erosion Shield Separation			x
Tail Rotor Control Failed	x		
Tail Rotor Control Fail		x	
Rotor Yoke Crack		x	
Tail Rotor Unbalance (Bush Migration)		x	
Rotor Trunnion Bolt Failure			x
Damper Attach Bracket Failure			x
Gearbox Failure	x		
Rotor Brake Fire		x	
Gearbox Failure		x	
Oil Cooler Drive Failure			x
Uncontained Gear Failure		x	
Tail Rotor Pitch Horn Failure		x	
Gearbox Failure	x		

APPENDIX VI

SUMMARY LIST OF RECOMMENDATIONS

RECOMMENDATION 1. That the CAA initiate a special study into the detail causes of the significant number of helicopter accidents attributed to "human error" to see where technology might contribute to useful improvement.

RECOMMENDATION 2. More attention should be paid by helicopter manufacturers, in cooperation with customers for their machines, to the realism of their fatigue test programmes on which component lives are determined, in relation to the actual usage to be made of the machine by the customer; and conversely the customer should satisfy himself in conjunction with the manufacturer when changing the use of a machine that the new use is still within the forecast flight profiles both in terms of severity and frequency.

RECOMMENDATION 3. A research programme should be established seeking to obtain in-flight recorded data of actual loadings and duty cycles achieved by realistic helicopter operations, and analyses should be published.

RECOMMENDATION 4. We recommend that before a new type of helicopter is introduced on to the British Register the manufacturer and operator should evolve a system, in conjunction with the CAA the better to review and take action upon service difficulties affecting airworthiness; where more than one operator is involved on a new type, the system should allow for cross feeding of knowledge and experience between operators.

RECOMMENDATION 5. The CAA should prepare and publish a Guide to the Establishment and Maintenance of Quality Control of Helicopters.

RECOMMENDATION 6. The CAA should develop a procedure for the approval by the helicopter manufacturer of manufacturers of gearboxes and other vital assemblies where these are not produced by the main manufacturer themselves.

RECOMMENDATION 7. A study should be initiated forthwith to identify suitable requirements for an improved standard of crashworthines of the structure as a whole, landing gear, seats and possible restraint systems, having regard to possible military-civil cooperation in this area.

RECOMMENDATION 8. Immediate steps should be taken to require better standards of crashworthiness of fuel tanks and fuel systems.

RECOMMENDATION 9. We propose that draft requirements covering Ditching be published at an early date to encourage technical consideration.

RECOMMENDATION 10. We propose that resolution of the problems of stability of a ditched helicopter be urgently pursued.

RECOMMENDATION 11. The CAA should set up a working party between experts in the Airworthiness Division, Ministry of Defence and selected specialists from universities and industry to draw up proposals or requirements for parameters to be measured and for new or improved condition monitoring devices or systems, to be widely publicised.

RECOMMENDATION 12. The CAA should draw the attention of the Science and Engineering Research Council to the benefits to be obtained by industry as a whole from supporting work in condition monitoring.

RECOMMENDATION 13. The CAA should draw the attention of a Learned Society (for example the Royal Aeronautical Society) to the need to stimulate developments in condition monitoring by the promotion of discussion or conferences.

RECOMMENDATION 14. The CAA should make arrangements for financial provision for sufficient increase in staff levels concerned with helicopters within the Airworthiness Division to enable the various new Requirements to be prepared and processed expeditiously; and consideration should be given to some of the associated research work being carried out on a consultant basis, for example using the skills of the College of Aeronautics or like bodies.

RECOMMENDATION 15. The CAA should discuss with the Ministry of Defence the setting up of some sort of formal collaboration on helicopter matters. This should include consideration of development of safety requirements and the exchange of appropriate in-service information.