THE STATUS OF HUMAN FACTORS IN CIVIL ROTORCRAFT SAFETY

Tim Hughes and David Ingram
Advanced Engineering Dept, GKN Westland Helicopters Ltd.,Yeovil, Somerset, UK.

Abstract

This paper examines the role of human factors in civil rotorcraft safety, notably the contribution of poor situation awareness, and high workload, to reduced safety. Evidence of the key issues is drawn from two studies sponsored by the UK Civil Aviation Authority (CAA). The first of these, performed by GKN Westland Helicopters Ltd with GEC Marconi Avionics (Ref 1), considered the factors contributing to 30 helicopter accidents in which fully functional helicopters either flew into the sea or ground or came close to doing so.

Key conclusions from a second study, a survey of workload and safety hazards in offshore operations (Ref 2), are also introduced. This study, carried out by the DERA Centre for Human Sciences at Farnborough, focused on in-flight paperwork but also covered many other safety issues.

In addition to the potential problems faced in helicopter operations the paper examines the contribution human factors can make towards the solution of these problems. In particular the rationale behind new airworthiness regulations proposed for the certification of the human factors design process in commercial fixed wing aircraft is discussed. The challenges of adapting these procedures to the rotorcraft environment are addressed.

Introduction

In 1992, an AS 332L Super Puma helicopter crashed into the UK North Sea en route from the Cormorant 'A' production platform to the Safe Supporter, a "Flotel" just 200 metres away. This aircraft had been engaged in similar shuttle tasks since leaving Sumburgh 4 hours earlier. The helicopter approached the Safe Supporter with a strong, gusting tail wind, lost airspeed and height and was unable to recover despite the application of full power by the pilot.

The accident investigation (Ref 3) found that the loss of the aircraft and the associated fatalities and injuries were due to a combination of factors, mainly related to the rapidly changing airspeed/groundspeed correlation caused by turning downwind. It was also noted in the accident report that several human factors, including fatigue and frustration, plus a demanding flying programme may have contributed significantly to the cause of the accident. The report included a recommendation that high priority should be given to research that sought to minimise workload, in particular due to administrative matters.

While each aviation accident has its own unique circumstances, this accident is perhaps typical of many surface collision accidents (both fixed and rotary wing) involving relatively modern, well equipped aircraft with well trained crews. Accidents of this type often result from a combination of crew misjudgment, aircraft performance limitations and operational circumstances. Human factors play a significant part in these accidents. This combination of causal factors, and particularly the strong human element, make such accidents difficult to prevent.

Whereas significant progress has been made in the reduction of aviation accidents caused by mechanical or avionic system failures, following the UK Helicopter Airworthiness Review Panel (HARP) report (Ref 4), those due to human factors have proved to be more difficult to tackle. As a result, this category of accidents has become proportionately more significant and greater attention is now being given to this area by aviation authorities and researchers.

Estimates vary, but it is generally accepted that somewhere in the region of 70% of all aviation accidents, involve either direct or indirect human errors in their causal sequence. (Ref 5). A worldwide survey of helicopter accidents and incidents in 1995, considered pilot error/misjudgment to be contributory to 90 out of the 209 (43%) events reported (Ref 6), although the potential contribution of human factors in helicopter accidents might be expected to be somewhat higher given the variability and harshness of the helicopter operating environment when compared to fixed wing aircraft.

The accident rate is already considered unacceptable by many. If the rate remains constant, predicted increases in the number of aircraft movements will result in a higher absolute number of occurrences. This could be potentially damaging to the helicopter industry which already has a poor safety reputation in the public eye.

Despite their contribution to reduced safety levels, it is likely that human operators will remain an integral part of helicopter flight operations for the foreseeable future because human skills, knowledge and flexibility will be required to cope with the unpredictable and dynamic operational environment. Therefore greater efforts are required to reduce the number of human factors accidents.

Effective selection and training strategies, and the use of crew resource management (CRM) techniques will go someway towards this. However, these strategies are widely in use today and notwithstanding possible improvements which could be made to improve these areas, the accident rate shows little sign of decreasing since their introduction. The greatest improvements in safety are likely to be achieved through changes to the application of human factors in the design and certification process.

Critical airborne systems incorporate, wherever possible, redundancy to allow for component failures. They are thoroughly assessed to ensure that a single failure can never be catastrophic. All system components are tightly specified, and the full system is tested with all components in place to ensure that their interactions and interfaces work with each other in practice. This design activity costs time and money to put in place yet its necessity is never questioned. Is it surprising therefore that the one system component (the human) which does not receive this tight control and development effort is now the part giving rise to the most problems? If any other system component was responsible for 70% of the accident rate, had a known high failure rate but was absolutely indispensable within the system design, the engineering world would not hesitate to invest time and money into solving the problem or ameliorating its consequences. However, the aviation world still tends to treat human factors as a peripheral activity to the main design effort. The human operator is arguably the most safety critical aspect of the design, yet frequently human factors personnel often have no signatory power or veto on design documents, and there are no firm requirements within the design process and no minimum standards for certification.

Proposals are being discussed within the regulatory authorities for a more thorough consideration of human factors as part of the type certification process (Ref 7). The applicability of these proposals to helicopters remains to be examined, and is one of the main themes of this paper.

However, before discussing the future, human factors problems particular to the rotorcraft industry should be highlighted. Two recent studies provide evidence of the central issues related to human factors in helicopter safety, principally related to offshore operations.

CAA Surface Collision Study

One of the Air Accident Investigation Branch (AAIB) recommendations arising from the Cormorant 'A' accident was that the CAA should investigate the possibility of raising the height (100 ft) at which the Automatic Voice Alerting Device (AVAD) provides a warning to the crew. Subsequent discussions with operators concluded that no simple improvements could be made, but that research should be conducted firstly to establish the nature and extent of the problem of helicopter surface collisions and secondly to examine the case for the provision of a more effective and discriminating warning system. In view of this, the CAA formulated the objectives of a research programme, as follows:

- To carry out a broader survey of accidents and incidents and examine each in greater depth.
- To identify any common features or characteristics of surface collision accidents/ incidents.
- To investigate whether currently available equipment could have prevented identified accidents and incidents.
- To recommend the functional requirements of a system capable of preventing surface collision accidents.

This section of the paper reports on the study jointly undertaken by GKN Westland Helicopters and GEC Marconi Avionics in response to this requirement (Ref 1). The paper concentrates on the second of these objectives as it provides significant evidence and conclusions on key helicopter related human factors issues.

The core of this study was the detailed analysis of 30 accidents/incidents in which fully functional helicopters either flew into the sea or ground, or came close to doing so, and the subsequent assessment of these details as entered into a computer database.

The 30 cases (this being the number deemed appropriate to the scale of the study) were selected from the following sources:

- The helicopter section of the World Airline Accident Summary (WAAS), 1965 to mid 1995 (Ref 8).
- CAA Mandatary Occurrence Reporting system (MOR's) (Ref 9).
- International Civil Airworthiness Organisation (ICAO) Accident Data Reporting and Entry Procedure (ADREP) (Ref 10).

and contained a mixed sample of accidents, i.e. over water, over land, into rising ground, loss of control due to disorientation or distraction or whiteout in snow. The relevant data from each of these reports was placed into a computer database of the following format:

(i) An introductory section detailing the basic facts regarding the occurrence, such as the activity being performed at the time of the accident/incident and the purpose of the flight.

(ii) A section containing details of the weather at the time of the occurrence. Such items as the wind speed and precipitation were noted.

(iii) Details of the visibility at the time of the accident. This section was designed to provide an indication of the quality of the visual cues available to the crew both from the external environment and within the cockpit.

(iv) A section outlining the workload, capabilities and interaction of the crew. Memo fields were provided in order to record any other relevant details regarding the crew members.

(v) Details of the autopilot, warnings, and IFR equipment fit of the aircraft along with an analysis of any problems associated with the displays and audio warnings.

(vi) A section detailing the aircraft's flight attitude and flight path at the point in the flight when it either impacted the surface, or at the crucial point of the flight that led to the accident/incident. This was designated the final critical point of the flight. Each of the flight parameters were recorded along with an assessment of whether the crew did, or could have had, knowledge of each of these parameters. Information provided by Cockpit Voice Recorders (CVR) and Flight Data Recorders (FDR) was very valuable here, if available.

Although the database was primarily intended for analysis of the use of technology to prevent or circumvent surface collision accidents, a number of very significant conclusions can be drawn from the circumstances of the accident and incidents analysed.

General Details

Twenty six of the 30 accidents/incidents occurred during visual contact flight. In all but one of these cases, cues from one or more aspects of the external environment were either degraded in quality in some way, or were non-existent. This illuminates a trend for crews to continue into conditions with poor external cues whilst still flying using external references. In many of these cases the safe option may have been to return to base or make a diversionary landing.

Of the 30 accident/incident cases examined, 25 occurred during controlled flight, i.e. when the aircraft performance parameters, attitude and response to controls were normal. In these cases lack of spatial awareness played an important part in the event.

Twelve of the 30 occurrences were in the approach/landing phase of flight. This may indicate a particular difficulty with the final phase of flight, when the aircraft is descending toward the surface possibly with very few or misleading external references.

Seventeen cases occurred over water, 10 over land and 3 over ice. This probably reflects the proportion of helicopter flights engaged in offshore operations.

Crew Workload and Procedures

In 27 of the 30 cases the handling pilot appeared to be devoting too little attention to monitoring the instruments and in 16 cases devoting too much attention to external monitoring. In many cases the crew's division of tasks had to be surmised due to lack of available information. Nevertheless, one factor that became apparent was that too little instrument monitoring was being performed. This may suggest that when poor visual conditions were encountered, there was a tendency to try and maintain contact with the external visual references, when in most cases considerably more attention should have been devoted to the instruments, some of which could have provided vital information that a dangerous situation was developing. It may also indicate that the presentation of flight data was not in a form that allowed ready assimilation at the time of the occurrence.

Similar comments can be made for the non-handling pilot. In 13 of the 15 cases where a non-handling pilot was present it appears that they were devoting too little attention to monitoring the instruments.

In 17 cases aspects of the flight at the time of the occurrence were covered by operational procedures. In 7 of these cases the procedures could have been improved. In the majority of these cases the Company Operating Manuals did not contain detailed or explicit instructions as to what should be done in the particular situations that led to the occurrences.

Weather and Visibility

Poor visibility appears to have played an important part in many of the occurrences. Table 1 below summarises aspects of the visibility for the thirty cases.

The most significant common factor seen in this table is the lack of external horizon cues, associated with degradation of other visual cues in most cases, which can lead to a poor perception of height and motion in visual contact flight.

Degradation of external visual cues can occur through atmospheric factors such as fog (12 cases), low cloud or snow, or through flight over featureless surfaces. In this respect flight over water when there is little wind leading to a glassy (4 cases) or calm surface (4 cases) appears to engender perceptual problems. Most of the 7 cases where the feature cues were described as misleading occurred during descent/approach (4 cases) or low level cruise (one case) with either glassy sea surfaces (3 cases), fog, snow or night time conditions. The same number of accident/incidents (14 cases) occurred during the day as at night with 2 occurring during dawn. No firm conclusions can be drawn from this fact as the overall ratio of day to night flights is not known, but in the UK approximately 15 to 20% of all offshore operations are at night. This varies seasonally from 30% in the winter to practically nothing in the summer. This would suggest that particular problems are experienced at night.

Flight Parameters

Lack of knowledge of each of the following flight parameters was a factor in a significant number of occurrences: altitude (27 cases); rate of descent (24 cases); aircraft pitch attitude (8 cases) and airspeed (8 cases).

Whilst lack of knowledge of a parameter may be a factor in the occurrence, the crew may not have been totally ignorant of it. In some cases the crew were partially aware of the parameter, in others they knew a value but were unaware of its significance, eg. wandering off course at a constant pressure altitude over rising ground.

In 18 of the 24 cases where lack of knowledge of rate of descent was a factor in the occurrence, the crew appeared to have no knowledge whatsoever of their rate of closure with the surface. In many cases this was due to the crew devoting too much attention to visual contact with poor external cues, and in others to the non-compelling nature of the rate of descent display, especially at low rates of descent. Similar comments apply for the 17 cases where the crew had no knowledge of the altitude in the 27 cases where lack of knowledge of height above the surface was a factor.

Due to the nature of the helicopter power/airspeed relationship and its method of control, airspeed and rate of descent are highly dependent on aircraft pitch attitude (controlled by the cyclic stick) as well as the collective position. In 8 of the cases investigated, failure to maintain the correct pitch attitude led to the aircraft flying too slowly and losing height or flying backwards (6 nose up cases), or losing height whilst flying at the correct speed (one nose down case). In one case the pitch attitude could not be ascertained from the report.

Table 1 Summary of Available Visual Cues for the 30 Cases

Cues	None	Degraded	Misleading	Good	Not Known
External	6	21		3	
Internal (within the cockpit)	9	18		3	
Surface	9	19		2	
Horizon	19	7		2	2
Feature	9	12	7	1	1

In all 8 cases where lack of knowledge of airspeed was a factor in the occurrence, the final critical airspeed was below 40 kts, i.e. the aircraft was flying in the low speed regime where measurement of airspeed can be unreliable. In some cases this lack of knowledge was due to the crew flying with visual reference to the ground without consideration of the effects of windspeed on their true airspeed. In these situations a method of presenting airspeed/ groundspeed correlation, combined with a reliable and accurate low airspeed measurement system, is required. Other cases were due to the crew being distracted from instrument monitoring through poor external viewing conditions.

CAA North Sea Helicopter Paperwork/ Workload Study

The CAA are concerned with the issue of workload in helicopter operations (in accordance with one of the recommendations in the Cormorant 'A' accident report) and commissioned a study to investigate the issue of workload in civil offshore operations. Particular attention was paid to in-flight paperwork and its influence on safety relative to other workload issues.

This study was carried out by the DERA Centre for Human Sciences with personnel from North Sea helicopter operators (Ref 2). The study results were gained from two forms of communication with operational aircrew; firstly detailed interviews were undertaken with 30 pilots before in-depth questionnaires were sent to all 380 CAA licensed pilots flying offshore missions in the UK.

Data analysis centred on a number of issues and considered whether and by how much they contributed to workload as well as their likely safety hazard.

Turbulence around platforms was found to be the most frequent cause of high workload, followed by weather conditions and completion of paperwork. This order of significance also applies to the safety hazard.

In flight completion of paperwork was found to affect piloting tasks, monitoring and CRM. The problem is exacerbated if the operation involves shuttle flights and multiple landings, if there is poor weather, it is night time, or if the crew are approaching a rig. Further contributory factors are late changes to missions, commercial pressures, poor cockpit lighting, poor helicopter landing officer service and lack of standardisation. The quantity of the paperwork itself, duplication of entries and its storage and handling were also considered problematic.

Although the safety hazard of paperwork can be reduced by deferring it to a more convenient time, the workload is still there. Of the more serious workload issues considered in this study, paperwork was thought to be the most easily addressable. Improvements that were suggested included reducing (including removing duplication) and standardising paperwork, having better storage facilities in the cockpit, computerising and automating some of the paperwork and minimising late changes to loads or routes.

Strategies for Addressing Human Factors Issues

The findings from the studies discussed above only serve to strengthen the evidence that human factors play a significant role in rotorcraft safety. Humans will remain part of the aviation system for the foreseeable future, so these issues must be addressed if we wish to achieve a safer aviation system.

There are basically two approaches to optimising the relationship between humans and their working environment, either fitting the person to the job or fitting the job to the person. Personnel selection and training are essentially concerned with the former and are important elements in any safe aviation system. However, despite likely improvements in training and selection techniques in the future we are unlikely to significantly change the human element of the system. The basic raw materials (i.e. humans) will remain constant, and they will continue to make mistakes from time to time. Therefore the only option is to adapt the machines to more closely match human capabilities. This has been termed 'human centred design'. This approach involves designing the system around the capabilities, expectations and limitations of the human operators from the beginning.

This does not reflect the traditional approach towards human factors. In the past human factors have often not been considered until late on in the design cycle. It is seen as an expensive overhead as the resulting safety improvements are difficult to quantify in the short term. The prevailing certification process has contributed to this lack of emphasis on human factors. Mandatory regulations will be required in order to establish a human centred approach.

The paper will go on to address the shortcomings of the current design and certification process as it relates to human factors and the proposed new certification requirements which have been designed to alleviate some of these issues will be examined. The implications of these proposals for the rotorcraft industry will be discussed.

The Current Status of Human Factors in Civil Rotorcraft Certification

The requirement to consider human factors in the design and operation of civil helicopters is documented within the existing type certification requirements. However, these requirements are very poorly expressed, often in general terms and they are distributed throughout several sections of the regulations. In JAR 27/29 most of the human factors related issues are covered by implicit requirements which are embedded in the sections concerned with flight deck interfaces. This is typical of the prevailing systems-oriented approach to certification, where the human performance effects of individual systems are considered in isolation. This approach fails to consider the broader consequences of the interactions between systems. Although the regulations do consider the design of cockpit controls and displays, the level of integration has now become so complex in many aircraft that the cockpit interface now warrants consideration as a combined system.

The regulations have not kept pace with changes in technology and increased knowledge about human performance. For example flight crew workload is the only major human performance consideration specified in existing Part 27/29 regulations; no consideration is given to important human factors issues such as the potential for designs to induce human error and to degrade situation awareness.

A number of further issues associated with the existing approach to human factors in the design and certification process have been identified. These will be covered briefly in the sections below.

Subjective Evaluation Criteria

A key difficulty in human factors certification is that many of the requirements are stated in subjective terms. In the absence of clear, objective, and quantifiable standards for evaluating human performance, individuals' opinions become the standard against which the design is measured. The subjective nature of existing regulations and the lack of agreed human factors assessment criteria can leave interpretation of the regulations open to debate and the personal preferences of the certifying personnel. Where the regulations are vague he/she has the final say over the suitability of a system. This can contribute to inconsistent regulatory decisions, and inconsistent means of compliance being imposed on the operators and manufacturers.

Some areas of human factors, such as anthropometrics, and the physical characteristics of displays and controls are well understood and have obvious evaluation criteria which can be expressed with mathematical precision. However, such precision has not been achieved with respect to cognitive functions such as workload and situation awareness. JAR 29 establishes workload as an important factor for certification (JAR29.1523), but nowhere does it specify how workload should be defined, or how it should be measured. One would expect a typical engineering specification to be far more precise, but when humans enter the equation the necessary criteria required to assess performance either do not exist or lack the required precision.

The human's role in the aviation system is becoming increasingly cognitive. Therefore to be a credible part of the design process, reliable and valid methods for the assessment of cognitive performance will be required. Currently there is no general agreement in this area on the measures themselves nor what constitutes acceptable performance. The development of practical metrics and measures for cognitive functions such as workload would therefore seem to be an area in which human factors as a profession must concentrate its efforts.

Outdated Regulations

The rotorcraft airworthiness regulations have also failed to keep pace with emerging flight deck technology. Harris (Ref 11) suggests that the existing human factors certification process is outdated as it reflects older cockpit designs where every system has its own dedicated controls and indicators. This is inadequate for assessing the airworthiness of the modern integrated cockpit. For example JAR 27/29 contains no information relating to electronic flight instrument systems (EFIS). The majority of future rotorcraft are likely to be equipped with glass cockpit technology due to the increasing demand for information integration in order to manage workload. Electromechanical displays may also prove to be more expensive to support and maintain than EFIS. However, the existing rotorcraft regulations are written around older generation display technology, with references to standard 'T' instrument layouts and electromechanical gauges. In order to design EFIS systems helicopter manufacturers must borrow from existing fixed wing design principles, certification requirements and advisory circulars. Differences in the way helicopters are operated and in particular the environmental conditions under which electronic displays must operate in helicopters call into question the ability to read fixed wing requirements directly across into rotary wing aircraft. The application of fixed wing display hardware in helicopters may lead to less than optimal performance in rotary wing cockpits. Specific certification requirements and design guidelines for helicopter electronic display hardware may need to be developed to support human factors certification activities.

There is also a danger that outdated requirements could restrict the application of new technology in future systems. Improving the certification process and revising existing criteria and methods will assist the manufacturers and the regulatory community in achieving the goal of incorporating desirable new technology, while maintaining or increasing aviation safety.

Certification Personnel

In the current rotorcraft certification process human factors evaluations are predominantly performed by test pilots. It has been suggested that they are often not up to date with the necessary information and human factors knowledge required to perform this function. Their judgements of human factors acceptability are often based on extrapolation of experience from previous systems to the new one. This assumes that this knowledge is transferable, which may not be the case for significant HMI changes such as the introduction of EFIS technology.

A further factor which affects human factors evaluations is that most official pilots in charge of flying the aircraft during certification have less than 200 hours experience in the aircraft (Ref 12). Evidence suggest that at this level they are far from having established stabilised expertise especially in advanced or glass cockpit aircraft. The nature of the errors committed by pilots is dependent on their level of expertise. Clearly some relationships between human error and the system design will only emerge in experienced pilots after extended exposure to the system. These are not going to be discovered in the existing certification process.

Test pilots are trained to assess systems from the point of view of the average pilot, but this is inevitably difficult to achieve. They are not a representative sample of the end users. They usually have considerably greater operational experience and skill levels than the pilots who will be flying the aircraft. They may approve systems which average pilots are not capable of coping with under day to day conditions. For a design to be truly user-centred, the eventual end users ought to be included in the design process. However, it has been argued that the involvement of the end users too early in the design process could have a negative effect, as end users are unlikely to make important advances since they are only likely to feel comfortable with equipment that seems familiar to them (Ref 13).

We therefore perhaps need to re-examine the role of pilots at different stages of the certification process. Test pilots could perhaps be most usefully employed early in the design process, while final acceptance of the system should be contingent on the demonstration of required performance by a sample of end users. However, a number of practical questions remain to be answered, such as, how do we ensure a representative sample of end users? What impact will cultural differences make? By whom should the panel of certification pilots be employed, and how should they be retained?

Timing of Human Factors Evaluation

Currently human factors evaluations are primarily conducted near the end of the design cycle. At this stage there is little that human factors evaluation can achieve as it is often too late to make desirable changes which may be identified during the evaluation. There have been calls for the industry to abandon this 'piecemeal, after the fact,' application of human factors (Ref 14). In order to achieve this, it has been suggested that the certification process should require proof of the application of human factors throughout the design process rather than certifying against hardware based requirements stated in subjective terms at the end of the design cycle, (Ref 15 & 16) This has been termed the 'Quality Assurance Approach' as it borrows the principle that if the process is optimised then the end product should be acceptable. This is the basis which underpins the proposed human factors certification requirements discussed below.

This approach has been common practice in the military for some time now with the introduction of standards (Ref 17 & 18) which call for the establishment of a Human Engineering Programme Plan (HEPP) to assist in the traceability of human factors design activities through the design cycle. The HEPP includes consideration of the required evaluation activities, responsibilities, timescales, products and deliverables. These standards call for considerable input from prospective end users which allows the design to be continually modified. Data from these evaluations contributes to a progressive acceptance of the human engineering aspects of the design and ultimately acceptance by the customer.

Retrofits and Cockpit Standardisation

Civil rotorcraft operators often add equipment to the manufacturer's supplied cockpit to meet particular operational requirements, with little integration with the existing aircraft systems. The primary consideration for the installations is minimal cost. The installations are however not always consistent with the manufacturer's original design philosophy. The FAA HF Team Report (Ref 19) reported concern at the potential safety implications of such cockpit modifications.

In some civil helicopter fleets this has resulted in there being no standard cockpit layout. For example the same aircraft types may be equipped with different generation navigation equipment and this equipment may be located in different physical locations from cockpit to cockpit. This lack of standardisation is at least a large training overhead if not a potential safety hazard. Inadvertent activation of the wrong function or reversion to familiar behaviour patterns under stressful conditions could contribute to flight crew errors and exacerbate problems encountered during flight.

The certification process has contributed to this lack of standardisation. Each aircraft modification has been approved and issued with a Supplemental Type Certificate (STC) yet the impact of the changes on the manufacturer's original cockpit design philosophy are often not adequately assessed during the retrofit process.

It is likely, that the majority of the human factors certification problems for rotorcraft will lie with existing fleets, as the rate of introduction of new aircraft into civil service is small and is likely to remain so. Chapman (Ref 20) has suggested that in the next few years the main European civil helicopter operators are unlikely to re-equip with new types and that the civil helicopter fleets that we have today will be largely with us for the next 20 years. The opportunity for entirely new designs will be few and far between. He goes on to suggest that the manufacturers should therefore perhaps take greater interest in their existing fleets and, instead of trying to sell new aircraft, they should be engineering schemes to improve the airworthiness of existing types.

This would seem to be a sensible and increasingly important suggestion for the future. However, there will doubtless be considerable reluctance from many manufacturers to becoming involved with the re-certification of customer initiated retrofits as these exercises will involve considerable expense. However, as helicopters with sophisticated integrated avionic systems enter civil service in the future, a paradoxical situation can be foreseen. It will become more important that the manufacturer is involved in system upgrades, yet it is likely that more stand-alone equipment may be retrofitted to the aircraft as customers will not be able to afford the integration costs. Given this likely picture of future civil helicopter operations the challenge will be to retrofit cockpit systems to keep the aircraft viable within the emerging air traffic environment. The future certification process will need to address these issues to ensure retrofits are consistent with the manufacturers' original design philosophies.

In the meantime what about the existing fleets? What measures can be put in place to ameliorate these standardisation problems? Operators should be encouraged to ensure commonality within aircraft fleets. Ergonomic 'audits', and operational requirement analyses could result in recommendations for optimised cockpit layouts for different existing types. Alternative solutions could include extending aircrew licensing to specific type variants, or dedicated type variant training. If implemented these measures should be backed up by regulatory authorities as operators are unlikely to act unless mandated to do so for safety reasons.

Human Factors Certification Initiatives

In an attempt to reduce the contribution of human factors to poor aviation safety the certification authorities have proposed changes to the certification requirements relating to civil flight decks (Ref 7). They propose regulation that includes the design process in favour of regulation of the detailed design alone. Regulating the detailed design could end up being unduly prescriptive in terms of technology, and therefore obstructive to technical progress and innovation. Emphasis on the process however offers a more practical approach than seeking detailed human factors certification criteria. In order to cover all eventualities these would become so complex and cumbersome as to be ineffective. The requirement to support high level human factors criteria with a sound development process is also not tied to particular technologies, and therefore will not become immediately outdated due to technical progress.

The proposed requirements are intended to improve the standard of human factors design in the flight deck. This in turn should increase safety by reducing those pilot errors which are caused by aspects of the flight deck design. The regulations will also encourage increased commonality, and standardisation of logic, although this is a complex issue which is tied in with commercial and marketing issues. The benefits to aircraft manufacturers of adopting this new approach will include a defined process which the authorities have agreed to accept, a flight deck design which can be justified by firm human factors evidence, improved end user attitudes towards the design and hopefully, a reduced rate of safety related occurrences.

Flight deck design, in this context, covers all aspects of the flight deck interface, ranging from the position of controls and displays for reach and vision, to the compatibility between avionic system operation, and the presentation of data on flight, navigation, engine and other system displays. All or any of these can contribute to crew workload and the potential for error.

Discussions so far have centred on the inclusion of these proposals within JAR 25 (large aeroplanes) because it has the largest potential effect on the commercial aerospace industry, but this is only to give a feel for how the regulatory material might be incorporated. Helicopters have not been specifically mentioned in the proposals to date, but it is intended that the new regulations would cover all types of aircraft, and that would imply parallel modifications to JAR 23 (small aircraft), 27, and 29, as well as 25.

It is expected that the same general structure will be applied to all types i.e. justifying the design in human factors terms, ensuring appropriate user involvement in the design, and providing evidence of the ease of use of the system, etc. Obviously minor adjustments will be required from type to type to account for the differences in scale, and the exact method of meeting the requirements will be agreed between the applicant and the certificating Authority on a case by case basis.

The proposed certification requirements (Ref 7) call for the applicant to demonstrate that the flight deck interface adequately addresses the foreseeable performance, capability and limitations of the flight crew. More specifically they call for the applicant to satisfy the Authority that a number of specific aspects of the flight deck have been addressed. These include:

- The ease of operation including any automated systems.

- The effects of crew errors in managing the aircraft systems including:
  - The likelihood of error.
  - The possible severity of the consequences of these errors.
  - The provision for recognition and recovery from error.

- Task sharing and distribution of workload between crew members during operation.

- The adequacy of feedback, including:
  - Clear and unambiguous presentation of information.
  - Representation of system condition by display of system status.
  - Indication of failure cases, including aircraft status.
  - Indications of when the crew inputs are not accepted by the system.
  - Indications of prolonged or severe compensatory action by a system when such action could adversely affect aircraft handling or safety.

The requirements will not only apply to new flight deck designs, but also to installation of supplementary equipment, and modifications under the supplementary type certification procedures. Where supplementary or modified features are presented, the requirements call for their assessment not to be limited to those features in isolation, but to also give due regard to their use as part of the integrated flight deck.

In order to demonstrate compliance with the requirements the manufacturers will be required to produce a documented plan of human factors development activities, to show how the high level criteria will be addressed. The regulations suggest that where design decisions may affect the safe conduct of the flight by the crew, they should be justified by a clear, documented rationale and, where appropriate, objective evidence from research, user evaluations or in service data. They go on to suggest that the Authority's Certification Team should be given the opportunity to monitor the development process against the plan, and to minimise the risk of requiring change at a late stage, they should be invited to attend scheduled evaluation trials. Acceptance of the product will be subject to assessment of the final completed design by the Authority's Certification Team. It should be noted that in order to allow applicants to plan their design activities with confidence they will need assurances from the certificating Authority regarding the availability of Authority personnel to participate in design evaluation activities.

In addition to changes to the regulations which deal with the requirements for the finished product the proposals also include changes to JAR 21 which regulates the process that all manufacturers must go through in order to achieve certification. In essence these regulations require that applications for certification must be accompanied by the civil equivalent of a Human Engineering Programme Plan (HEPP). The manufacturer will be required to demonstrate adherence to the plan throughout the design process. Adherence to the plan will be monitored and acceptance of the product will be subject to the Authority's assessment of the final completed design, not merely the combination of assessments of individual features.

It is suggested that an acceptable plan should include:

- The scope and organisation of the resources required for the design and evaluation of human performance and limitations aspects of the fight deck.
- The means by which the flight deck interface design, and changes to the design, will be authorised within the applicant's organisation.
- The development schedule, including milestones and reviews.
- The functional philosophy for flight deck design and any integrated automation which will be used and applied by all relevant parts of the organisation, including sub contractors.
- The means of evaluation, including details of subject flight crew proposed for structured trials, and the levels of simulation to be employed.
- The means of systematic evaluation of the effects of flight crew error.
- Details of configuration control methods.
- Details of supporting information to be used, including research results and in-service reports.
- The methods for evaluation of training effectiveness, under normal and abnormal circumstances.
- The means of evaluating operational suitability, including integration with current or proposed navigation and communication systems.

The plan is not intended to be a rigid document and it is proposed to allow amendments to it, if they are justified, documented and agreed by the Certification Team. However, adherence to the accepted plan will be monitored by the Authority.

A central theme of the regulations is that they mandate the incorporation of pilot opinion throughout the design process, ensuring that the design meets the expectations, capabilities and limitations of the target population of end users. This can be best achieved through system representations receiving timely evaluation by qualified test pilots, and the structured involvement of operational users (e.g. performance on part task simulation) throughout system development. It is suggested that features which are novel in concept or in presentation should receive particular attention.

These proposals have been largely well received on both sides of the Atlantic. They have been recommended for further action by the JAA Human Factors Steering Group and are currently under discussion by a FAA/JAA Joint Task Force which will examine the issues involved in implementing these proposals with the aim of establishing a common regulatory approach. The time scales for this process are somewhat unclear and may be complicated by FAA industry consultation procedures. However, the best guess of the regulatory authorities at present is that they expect the new regulations to come into force by the millennium.

The Impact on Rotorcraft of the Proposed Human Factors Certification Requirements

The likely time scale for the introduction of the certification proposals discussed above makes them a live issue for which the helicopter industry ought to be preparing itself right now. One of the largest problems facing human factors certification in rotorcraft will be the costs that could be associated with its introduction in whatever form it is implemented.

The initiative for human factors certification has grown from the high capacity civil fixed wing sector. This sector is perceived as better able to afford such an initiative. The initial investment required presents less of a problem in this market where the scale of operations allows the costs to be amortised over larger numbers of aircraft, and faster returns can be made on investments. However, the application of these proposals in helicopters, lower capacity fixed wing operations, and general aviation, may prove more difficult. In these types of operation the economic margins are extremely constrained and investment is much harder to justify.

The helicopter industry is already sensitive to cost. Helicopters are perceived as very expensive to buy and maintain. Anything which is likely to add cost must have a perceived benefit to the operator. Unfortunately the cost benefits of improved safety resulting from the application of human factors are very difficult to demonstrate in the short term.

The proposed process discussed above assumes that certification activities will be integrated into the design process. Manufacturers will no doubt be nervous of being required to make significant investments in facilities and resources such as simulators and rapid prototyping tools to support this process. Such tools will undoubtedly be useful in this process, however many of the required human factors activities could be achieved at lower cost. In advance of the regulations coming into effect the industry needs to understand exactly what level of resources and technical support is actually required to meet these requirements.

The manufacturers will also be concerned that the involvement of the regulatory authority throughout the design phase will expose them to greater expense and possible time delays due to continual requests for changes. However, careful consideration should indicate that in fact the risks to the manufacturers are greatly reduced by these proposals. The plan of development activity would be agreed early in the programme, such that the manufacturer would have a clear overview of what was required. Discussion items would become less subjective. Any features that are likely to be unacceptable to the authorities will be identified early, and can therefore be addressed before costs and delays become prohibitive. The risk that the completed product would face rejection at the certification stage would progressively diminish as the design progressed.

Despite the initial investment, significant life cycle cost benefits can be demonstrated from the early integration of certification activities in the design cycle, which in turn could reduce costs to the customer in the long term.

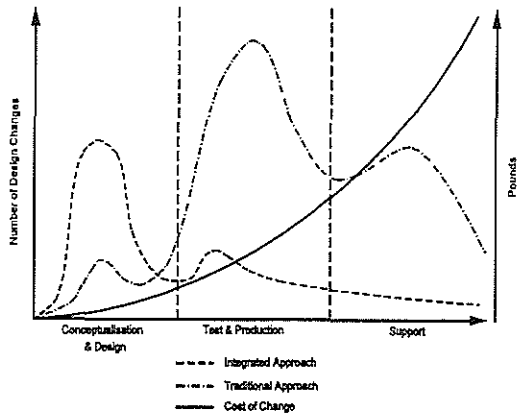

Figure 1. The Costs associated with a Traditional versus an Integrated Human Factors Certification Process

Figure 1 indicates the predicted number of design changes which would be made with an integrated approach and the number of changes made with the current process. This is overlaid with a curve showing the increased cost of change throughout the product life cycle. Clearly whilst there are significant costs associated with the integrated approach early in development, these are far outweighed by the costs incurred by the traditional approach later in the life cycle. Unfortunately, however, there is still likely to be considerable inertia within the helicopter industry to the acceptance of such new processes due to a lack of recognition of the benefits that this approach can bring.

Regulations will obviously be required to establish the scope of human factors certification activities, but they will need to reflect a balance between what is required and what is economically feasible in order to gain acceptance in the rotorcraft industry. The industry must be educated to the benefits of this integrated approach to human factors certification and encouraged to make a leap of faith.

Conclusions

Two studies recently carried out for the CAA have shown that human factors play a large role in the safety of helicopter operations. The application of human factors in design is perhaps of greater importance in helicopters than in many other areas of the aerospace system due to the operational environment in which they operate. Yet despite this recognition, human factors still seems to be of peripheral concern to many manufacturers, and is poorly addressed by the current regulatory processes (Ref 21). Human factors in aviation safety are currently high on the international agenda, but much of the effort is concentrated in the fixed wing world. It remains to be seen to what extent these processes will be adopted for the rotary wing environment. There is scope for a large degree of commonality, yet the economic factors affecting helicopter operations will influence the way in which they are implemented. Further effort perhaps needs to be invested in ensuring the human factors considerations of helicopter operations are fully considered.

In March 1997 a workshop was held to discuss the issues surrounding human factors certification. The invited international audience included many respected figures from the human factors community. However the workshop concentrated on fixed wing civil transport operations and the helicopter industry was poorly represented. It became clear that there are a number of areas in which helicopter operations differ from large fixed wings which could significantly influence the certification process. It was suggested that a similar workshop, concentrating on the issues for helicopters ought to be convened to highlight the proposed changes in certification procedures to the helicopter industry at large. This conference could be influential in shaping the human factors certification requirements as they apply to helicopters.

One of the central problems associated with human factors certification in the helicopter industry is that the safety benefits associated with good human factors design and certification procedures are difficult to quantify which makes the necessary investment difficult to justify. Convincing manufacturers and operators to implement schemes to meet human factors requirements will be difficult and a certain amount of inertia to the acceptance of these proposals can be expected.

A phased approach to adopting the new procedures seems inevitable. It is likely that technical and financial resources for this initiative will be limited, and in practice, valid certification criteria and human factors assessment techniques are far from established in many areas of human performance. Guidance will be required to concentrate efforts in the correct areas for maximum gain. Specific issues such as the assessment of workload, situation awareness, human error, automation philosophy, and cultural factors will be especially significant in future rotorcraft, as will the application of human factors certification procedures to cockpit retrofit programmes. The challenge will be for the manufacturers, customers and the regulatory authorities together, to create an infrastructure within which the needs of all parties can be met.

In the future human factors must be taken seriously. If we are going to reduce the accident rate, it must be a mandatory part of development in the same way that testing for structural and mechanical stress, software, and avionics integration is today.

Acknowledgements

The authors gratefully acknowledge the UK CAA for actively promoting research work into helicopter human factors issues and funding the investigation into helicopter surface collision accidents. Also recognised are the time and effort given by the airworthiness authorities of Australia, Canada, Germany, Spain, Scandinavia and the USA in providing information and accident investigation reports for the surface collision study. The contribution of Ken Smart of the UK Air Accidents Investigation Branch (AAIB) in facilitating database searches is particularly appreciated.

The authors would also like to acknowledge David Howson and Hazel Courteney of the CAA for providing copies of the North Sea paperwork/ workload study, and the human factors certification proposals respectively.

References

1. Bowhay, D.A., Ingram, D.B., Martin, C.R., & Martin, J.H. (1996). *Investigation and Review of Helicopter Accidents Involving Surface Collision.* Final Report, CAA Contract No 8D/S/00002. Vol 1 & 2, GKN Westland Helicopters Document No RP981, September 1996.
2. James, M., Scriven, J., Green, R. (1997). *A Questionnaire Survey of Workload and Safety Hazards Associated with North Sea and Irish Sea Helicopter Operations*. (DERA Centre for Human Sciences). CAA Paper No. 97009.
3. Air Accidents Investigations Branch (1993). *Report on the Accident to AS332L Super Puma, G-TIGH, near the Cormorant 'A' Platform, East Shetland Basin on 14th March 1992*. Aircraft Accidents Report 2/93, April, 1993.
4. Helicopter Airworthiness Review Panel. Civil Aviation Authority CAP 491. June 1984.

5. Courteney, H.Y. (1995) Flight deck Certification-A Way Ahead? In *'Low Cost Avionics - Can We Afford It?* the Proceedings of the ERA Conference, Ramada Hotel, Heathrow, UK. November 1995.
6. Learmount, D. (1996) Safety Circles, *Flight International,* 16-22 October 1996
7. Courteney, H. Y. (In Press) Project Requirements: The Silent Dictators. *Proceedings of the Allocation of Function Conference 1997*, University of Galway, Republic of Ireland.
8. Civil Aviation Authority Paper, *'World Aircraft Accident Summary', CAP 479, Issue 10/95, plus supplement No. 99.* August 1995.
9. Civil Aviation Authority Mandatory Occurrence Reporting system (MOR's).
10. International Civil Airworthiness Organisation (ICAO) Accident Data Reporting and Entry Procedure (ADREP).
11. Harris, D. (1996) Certification of the Human machine interface for civil Flight Decks. *In Proceedings of Airworthiness Aspects of New Technology.* An I Mech E Aerospace Industries Division Seminar. 20th Nov 1996, University of Bristol, UK.
12. Amalberti, R. & Wilbaux, F.(1994) Advanced Glass Cockpit Certification: Wariness About Human Factors. In *Human Factors Certification of Advanced Aviation Systems* edited by J.A. Wise, V.D. Hopkin and D. Garland. Embry-Riddle Aeronautical University Press.
13. DuJardin, P. (1993) The inclusion of future users in the design and evaluation process. *Le Transpondeur,* April, pp.36-39.
14. Butler, J. (1994) *Shell Aviation Safety Conference Proceedings.* Shell Aircraft Ltd.
15. Taylor, R.M. & MacLeod, I.S. (1994) Quality Assurance and Risk Management: Perspectives on Human Factors Certification of Advanced Aviation Systems. In *Human Factors Certification of Advanced Aviation Systems* edited by J.A. Wise, V.D. Hopkin and D. Garland. Embry-Riddle Aeronautical University Press.
16. Hopkin, V.D., (1 994) Optimising Human Factors Contributions. In *Human Factors Certification of Advanced Aviation Systems* edited by J.A. Wise, V.D. Hopkin and D.Garland. Embry-Riddle Aeronautical University Press.
17. Mil-H-46855 *Human Engineering Requirements for Military Systems, Equipment and Facilities.*
18. STANNAG 3994 *The Appication of Human Engineering to Advanced Aircrew Systems.* (NATO).
19. FAA Human Factors Team Report (1996) *The Interfaces between Humans and Modern Flight Deck Systems,* July 1996. Federal Aviation Administration. United States.
20. Chapman, D.J. (1996) The Way Forward in Helicopter Safety. In the *Proceedings of the Shell Aircraft Aviation Safety Conference. 1996.*
21. Courteney, H.Y. (1996) Practising What We Preach. In *Proceedings of 1st International Conference of Engineering Psychology.* Stratford on Avon, UK. Oct. 1996.