39th European Rotorcraft Forum Sept, 2013 Paper No 055

THE UK MOD HELICOPTER SAFETY ENHANCEMENT PROGRAMME

Pat Collins, Science Gateway, **Stuart Long**, Safety Team Leader, & **Gareth Rudge**, Safety Compliance, Helicopters Operating Centre, Defence Equipment & Support, Bristol, UK
Bryan Finlay, Capability Advisor, Defence Science & Technology Laboratory, Fareham, UK

Abstract

Operation of helicopters in a military environment presents a number of hazards; some of which (for example hostile fire, weapon misfire) are uniquely military. However, the UK Ministry of Defence (MOD) experience is that a significant proportion of the risk to life arises from aviation operating issues common to civilian helicopter operations. Of these risks; Wire-strike, Mid-Air Collision and the impact of operation in a Degraded Visual Environment (DVE) have been identified as the three primary risks to safe operation. A number of mitigations have been considered to meet these risks with the most appropriate for each platform planned for progression; this could result in differences in the equipment delivered between helicopter types to address the same risk. This paper provides a brief overview of helicopters operated by the UK MOD and provides details of activities, to date and planned, in support of the Helicopter Safety Enhancement Programme. Over the next few years the UK MOD will, subject to the outcomes of cost benefit analysis increasingly equip their helicopter fleet with mechanical wire cutters and electronic aids that will assist in wire identification, reducing significantly the probability of loss from wire strike. Research is ongoing to identify suitable systems to reduce the probability of mid-air collisions between UK MOD helicopters and other military and civilian air vehicles (both manned and unmanned) in permissive and non-permissive environments. Operations in current theatres have identified the reduction in visual cues whilst operating close to the ground, particularly during landings at un-prepared sites as a significant hazard; the current programme is developing means to reduce the risk of these operations for helicopters through symbology systems and Digital Automatic Flying Control Systems (DAFCS) with high order autopilot modes.

1. INTRODUCTION

1.1 Military Helicopter Operations within the UK

The UK MOD operates a fleet of more than 400 helicopters[1] of many different types providing a range of capabilities that can be categorised as Lift (transport of people and equipment), Find (reconnaissance) and Attack. These are operated by all three services (Army, Royal Air Force and Royal Navy) with some overlap of tasking between the services. A revised strategy agreed through the 2010 Strategic Defence and Security Review (SDSR) aims to reduce the number of different types in service, with an aspiration to reduce to five core types by 2020. This will see the introduction of new helicopters (Chinook and Wildcat), upgrading of some existing types (Apache, Chinook, Merlin and Puma) and retirement of others (Gazelle, Lynx and SeaKing). The upgraded Pumas, due to enter service in the near future, are scheduled to remain in service until 2025 after which time they will be withdrawn allowing a further consolidation to four core types; the majority of which are likely to remain in service until at least 2030 and most likely 2040.

In addition to the core fleets there are a number of other helicopter types used to support a range of training, liaison and other roles. For example; initial pilot training is conducted at the Defence Helicopter Flying School which is operated by FB Heliservices under contract from UK MOD; the school's helicopters are military registered but civilian owned.

1.2 MOD Organisation

The organisation of the MOD has recently undergone a major change with responsibility for provision of military capability moving from central staff to four Front Line Commands (FLC). The vast majority of the helicopter fleet sits within three: Air Command has responsibility for the training fleet; Land Command are the parent body of the Joint Helicopter Command (JHC), which overseas all helicopter operations, with the exception of "traditional" maritime activities delivered by Navy Command. The FLCs are in effect the owners of all military equipment within the UK and provide the skilled military manpower necessary to both operate that equipment and complete front line maintenance.

Responsibility for the procurement and support of equipment lies with the Defence Equipment and Support (DE&S) organisation. The Helicopters Operating Centre, one of 10 operating centres within DE&S, conducts acquisition and in service support of all UK military helicopters and leads the

Helicopter Safety Enhancement Programme that is the subject of this paper, on behalf of MOD.

Approximately 2% of the MOD budget is spent on Research and Technology (R&T). The Defence Science and Technology Laboratory (Dstl) has responsibility to maximise the impact of science and technology for the defence and security of the UK and is responsible for managing the core research programme funded by the MOD's Chief Scientific Advisor (CSA) along with additional funds from the defence equipment programme. The CSA programme represents around half of the total R&D funding, the remainder predominantly coming from the equipment programme. Considerable preliminary research that has supported the safety enhancements reported here was initially funded from the research programme.

1.3 Formation of the MAA

On the 2nd September 2006; XV230, a Nimrod surveillance aircraft operated by the RAF crashed during a mission over Afghanistan when it suffered a catastrophic mid-air fire with the loss of all 14 service personnel on board. Following a seven month long Board of Inquiry it was concluded that the most probable cause of the fire was the escape of fuel within the aircraft, following Air-to-Air refuelling, coming into contact with a hot metallic duct.

A formal review of the incident, chaired by Charles Haddon-Cave QC[2] has had a profound effect on airworthiness and safety within the UK. Among the recommendations were that "the MOD (to) build a New Military Airworthiness Regime which is effective, relevant and understood, which properly addresses Risk to Life, and which drives new attitudes, behaviours and a new Safety Culture". In addition it was recommended that "a new independent Military Airworthiness Authority (MAA) and Regulator (to) govern all aspects of military aviation…" Formation of the Military Aviation Authority (MAA) can be directly attributed to the outcome of the Haddon-Cave review.

1.3.1 Aviation Duty Holders

The UK MOD has introduced a series of Duty Holders who are responsible for actively managing Air Safety. There are several levels of Duty Holder[3] starting with the Senior Duty Holder (SDH) who is typically a 4* military officer responsible directly to the Secretary of State for Defence, the SDHs are the chiefs of the four FLCs. They appoint Operational Duty Holders (ODH, 2* operators), responsible for the airworthiness and safe operation of systems in their defined area of responsibility. For most UK helicopters this is the Commander of the JHC although Navy command's ODH also has responsibility for a significant number of helicopters. The SDH will also appoint Delivery Duty Holders (DDH) who would typically be a station or force commander accountable to their designated ODH on matters of Air Safety.

Operating Risks are owned and managed by the Duty Holder who is personally and legally responsible for ensuring that the Risk to Life (RtL) emanating from activities associated with their generation and sustainment of force elements is at least Tolerable and As Low As Reasonably Practicable (ALARP). If an identified Risk to Life (RtL) is not demonstrably at least Tolerable or ALARP then those activities should not continue. These responsibilities and the consideration of Risk to Life by the Operational Duty Holder continue to ensure that the UK MOD holds helicopter operating safety as a high priority.

2. IDENTIFICATION OF RISKS

2.1 Historical Analysis

Analysing incident data from the recent past provides a good indication of the risk of helicopter losses and associated causes. Recent UK MOD helicopter operations provide a small sample set for assessing risk exposure. Consequently it is more informative to look at data for a larger fleet with a much greater number of flying hours. In 2009 the US conducted a study to look at safety and survivability of rotorcraft focussed on operations in support of Operations Enduring Freedom (OEF) and Iraqi Freedom (OIF)[4] covering October 2001 to September 2009. The study looked at 375 rotorcraft losses from in excess of 11.2 million flying hours. A summary of the losses is given in Table 1. The study concluded that the fatality rates are 3-4 times greater in a combat theatre than out of theatre.

	Losses	Fatalities	Flight Hours
Combat Hostile Action	70	145	3,026,483
Combat Non-Hostile	157	219	3,026,483
Non-Combat	148	132	8,176,645

Table 1: US Helicopter losses in OEF/OIF 2001- 9

The US analysis further broke down the causes of fatality into a range of factors, approximately 2/3 of which related to human factors in cruise flight. The leading causes of incidents/fatalities were inadvertently flying into "Instrument Met Conditions" (IMC), Controlled Flight Into Terrain (CFIT), Mid Air Collision and Wire Strikes.

The UK MAA has conducted analysis of fatal military accidents since 1985, the data includes all types of platform operated by all three services but does not include any operational losses. Figure 1 provides the top level findings of their analysis which indicates that human factors (labelled as HF(A) in the figure) account for at least 65% of all accidents over the period. This is broadly in line with the US figures for fatalities although there are marked differences in the US data between cruise flight and hover/low speed events.

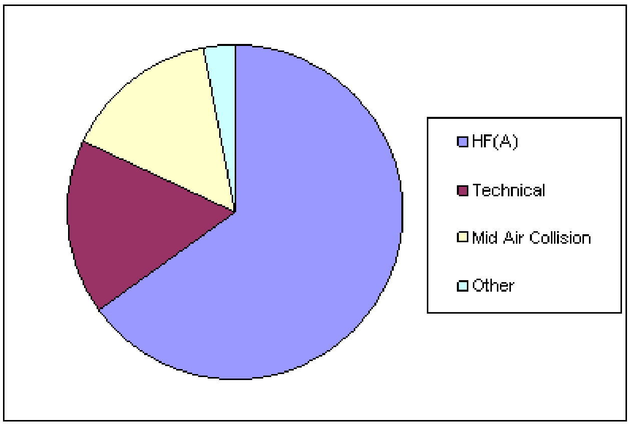

Figure 1: Causes of Military Aircraft Accidents since 1985 (image courtesy of MAA).

2.2 ODH Identified Key Risks to Life

Risk analysis has identified that UK MOD rotary operations are subject to three significant risks. These are currently owned at ODH level by Commander JHC who carries the highest exposure due to the number, size and role of the air-systems within his area of responsibility. The risks relate to mid–air collisions, wire strikes and operation in Degraded Visual Environments (DVE). A DVE is defined as one where visual cueing is reduced such that it adversely effects the pilots ability to control the helicopter. Figures 2, 3 and 4 provide some analysis of UK MOD incidents between 2008 and 2012.

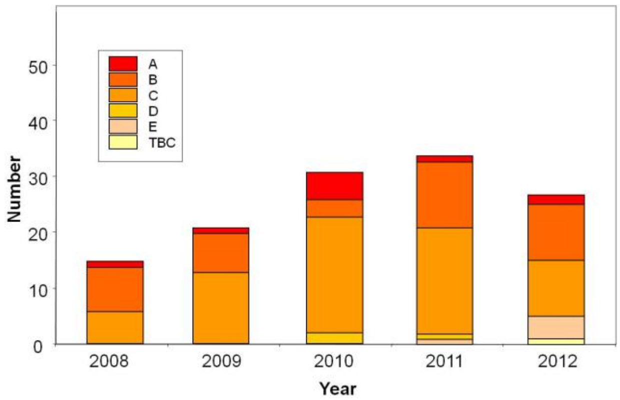

Figure 2: JHC "Airprox" Incidents, note that letters A-E are incident categories as defined by the UK Airprox Board; Category A relates to a situation where an actual risk of collision existed whilst category B relates to the safety of the aircraft not being assured based on the judgement of the UK Airprox Board. (image courtesy of Dstl produced using data provided by RAF Air Safety)

It should be noted that Figure 2 shows "Airprox" incidents occurring within UK airspace only. Data relating to "Airprox" incidents involving UK helicopters in operational theatres is limited prior to the middle of 2010; this identified 33 incidents in 2011 (11 of which were classed as Cat A (an actual risk of collision existed)) and 20 in 2012 (5 Cat A).

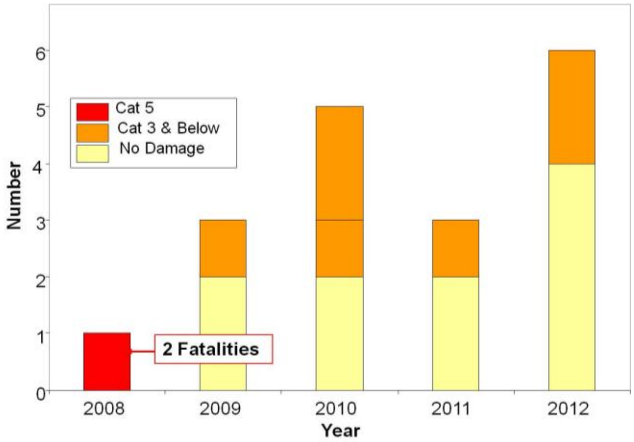

Figure 3: JHC Wirestrike Incidents, note that there were two fatalities directly attributable to Wirestrike in 2008. The damage categories used here (and in figure 4) are: Cat 5 – Beyond economic repair, Cat 4 – Repairable but requires specific facilities, Cat 3 – Repairable on site. (image courtesy of Dstl using data provided by JHC)

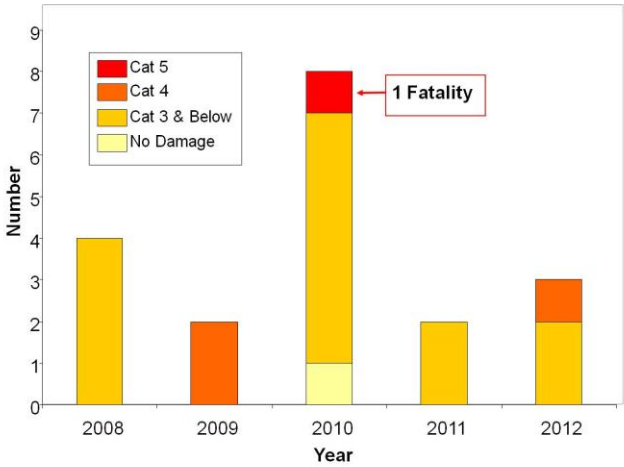

Figure 4: JHC Brownout Incidents, note single fatality in 2010 (image courtesy of Dstl using data provided by JHC)

The aggregation of DDH risks across all of the fleets has highlighted that the combined effects of wire strikes, mid air collision and operations in DVE close to the ground make the overall senior commander's risk significant. Additional focus has been brought to bear through UK airspace incidents being widely reported as well as occurrences during current and high tempo operations. In the context of the developments in performance, functionality and accessibility of equipment (particularly that available for general aviation) it is important that the tolerability of such risks is reviewed and, where practicable, equipment mitigations sought.

3. DESIGN AIRWORTHINESS Vs OPERATING RISK

The approach to aircraft design has from the outset been governed by regulation. For the UK this started with "The Handbook of Strength Calculations" in 1924, a document that has been modified over time to Defence Standard 00-970 – still the key design code for UK military aircraft required by MAA Regulation. Other design codes exist, for example the FAR 29 and EASA CS29 civil documents.

Whilst these codes appear very different in content, they share an underlying philosophy; that the core design of the aircraft should focus on identifying, understanding and managing the hazards associated with technical failure. This philosophy is explicit in the process documents that support the design and certification activity. ARP 4761 (Civil), MIL STD 882 (US Military) and Defence Standard 00-56 (UK) all address the core design target and the contribution that technical failure makes to this case.

Whilst human interaction is a core part of the equipment design and safety analysis, this analysis typically drives for the improvement of integrity of the air system over reducing operating risks. In the UK, the conclusion of the design and certification process results in military type certification and Release To Service (RTS) of the aircraft. At this point the Duty Holder is formally handed the air system safety case. However, as can be seen in Figure 1, over half of the likely accidents are driven by human factors rather than the technical failures that the design process has striven so hard to reduce. These *operating risks* are the main contributor to the risk to life that an operator is exposed to.

Predominantly aircraft on the UK military register are procured for the delivery of military capability. The vast majority of these aircraft are designed from the outset with to fulfil these military tasks; however a percentage of the fleet is made up of civil types adapted for military roles. There is a balance in the procurement process for aircraft between funding military capability improvements and funding the reduction of *operating risk*. The procurement of measures to reduce operating risk can be subject to two other factors that have traditionally affected the argument for their incorporation:

- Firstly, the inclusion of additional systems in the aircraft to address operating risk can, ironically, affect the equipment safety argument by generating more potential for technical failure;
- Secondly, the equipment focus of design teams can lead to attempts to solve issues solely through the introduction of technology – leading to complex and expensive modifications that are less likely to win approval.

In summary, military aviation has previously focussed on the integrity of technical design and mitigation of equipment failure as the primary means for reducing *operating risk*. This approach was appropriate given the learning curve that occurred in the last century as design practice evolved in understanding materials, stability and aerodynamic effects. However, this focus has reached a point where, although setting and achieving appropriate technical integrity must continue to be a priority, it has been recognised that there needs to be an additional focus – on reducing the *operating risk* that forms the predominant contributor to loss of life.

The UK Helicopter Safety Enhancement Programme provides an opportunity to take a more holistic approach and to actively reduce the risk borne by the Duty Holders through equipment mitigations.

Early requirements definition by duty holders naturally focussed on the equipment types which they had become aware of and the perceived immediate benefit for the lowest cost that these could offer. Where these were portable "carry-on" type equipments rapid assessment of the achievable functionality and design requirements for an airworthy integration were required to inform decisions for immediate mitigations.

A key principle of the short term mitigation is the AVOID strategy where carry-on hardware and Commercial Off The Shelf (COTS) software provide equipment options to avoid entering a position where the aircraft is exposed to the operating risk. Key constraints to achieve integration/fielding of this equipment include:

- Military Type Certification Requirements
- Hardware suitability
- Software integrity
- Internal antenna performance
- Electromagnetic Radiation Emitters
- Human factors including operator workload

- Security – not design airworthiness but a fit for purpose consideration

The trade off between operating risk and design airworthiness is also a key consideration for the complex mitigations.

Systems are now offering, or have the potential to offer, performance and functionality which provide credible mitigation to the operating risks of the military environment. However these are not yet developed at the level of integrity that enables sole reliance and as such the benefit they achieve is constrained but not always unacceptably. Two key points need to be addressed in order to arrive at a robust and acceptable solution, these are:

- Clear definition of the requirement and robust consideration of the functionality and integrity that enables the equipment to address the requirement.
- Where the demands on integrity/functionality drive an equipment type out of consideration revisiting the requirement may show that a useful level of mitigation can be achieved with simpler functionality or lower integrity.

Finally the analysis method used in assessing the suitability of any solution must clearly separate the derivation of the operating risk and the risk of a hazardous event from a failure of the mitigation. For example, it is necessary to ensure that the fitment and subsequent failure of an airborne collision avoidance system does not become the primary cause of a mid-air collision through aircrew relying primarily on the system rather than spending sufficient time “eyes-out”.

4. COST BENEFIT ANALYSIS

At an early stage in the programme preliminary Cost Benefit Analyses (CBA) were conducted to enable the MOD to prioritise potential risk mitigation technologies. Dstl concentrated on wire strike protection and mid-air collision avoidance measures, with DE&S assessing mitigations for operation in DVE. All of the analysis conducted followed MAA regulation[5] on how to conduct quantitative cost benefit analysis of potential air safety risk mitigation measures. For the purposes of this paper the methodology used by Dstl will be described to illustrate the process.

The probability of occurrence for an accident was assessed for a range of representative scenarios, which included both the most likely and worst credible cases. The study used historic helicopter incident and accident data to establish an accident rate per flying hour. This method relies on a relatively small sample of historic events and the need to ensure that the calculated accident rate is relevant to future operating scenarios. An alternative method would have been to rely wholly on qualitative Subject Matter Expert (SME) judgement as is often used to assess these operating risks. Quantitative simulation based methods, more normally associated with determining the probability of technical failure, offer yet another analysis technique. Initially CBA did not use these methods, but subsequent analysis by DE&S and Duty Holders are exploiting these techniques, with validation against the historic record. The rates used in the analysis are shown in Table 2.

Period Considered	Past 20 years
Wire Strike Risk per Flying Hour	1.02099E-05
Mid-Air Collision Risk per Flying Hour	1.70466E-06

Table 2: Derived Accident rates used in Cost Benefit Analysis

The accident rate and casualties associated with wire strike and mid-air collision over the past 20 years were analysed. Although there were year on year variations, it was established that the accident rates converged over time to relatively steady state values as shown in Figure 5.

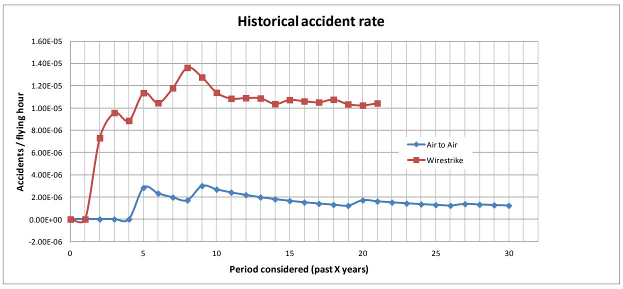

Figure 5: Historical Accident Rate Data used in Cost Benefit Analysis (image courtesy of Dstl)

This accident risk per flying hour was then applied to all aircraft within the UK MOD Helicopter fleet, with a specific weighting applied to each helicopter type, to account for the relative exposure to risk. In considering these weightings a range of key factors were taken into account such as: certain platforms operate in locations where wires are not prevalent, some platforms operate mainly at medium to high level or over water, and training fleet low flying is usually at a greater height above ground level than low flying for operational types. Factors taken into account for mid-air collision include low level flying, night flying, use of Night Vision Goggles, operation in congested airspace, crew composition, aircrew experience and the availability of radar in the air search mode. The weightings were developed by a panel of military advisors embedded within the analysis team at Dstl and varied between 100% (no reduction in risk) to 20% (significant reduction could be applied due to role, location equipment fit, etc).

The risk to life for mid-air collision and wire strike was calculated for each platform using the derived accident rate, the risk factor, future flying hour budgets, the number of crews, and a “fatality figure”. The fatality figure was based on the accident analysis which showed the percentage of wire strikes and for mid-air collisions which resulted in fatalities – not every case was fatal. DE&S has also completed further analysis to account for distribution of the probability of an accident and the numbers of fatalities that could result.

The analysis showed where the cost of modifications was not disproportionate to the reduction in operating risk. These cases tended to be platforms which carry a large number of people, had significant service life remaining and which were shown to be insensitive to the assumptions made within the analysis (through sensitivity analysis) or where the costs of the mitigation were low, for example the introduction of “carry-on” equipment.

For some platforms, where the remaining service life was short or specific risk exposure is low, the CBA showed that the cost of modification was not justified by the CBA alone. In these cases, societal considerations may drive the Duty Holder to commit to the introduction of mitigations. Other platforms which have been seen to be sensitive to the assumptions require further detailed consideration to ensure that the CBA was robust, where a societal argument was not solely sufficient to support an investment decision.

5. TECHNICAL SOLUTIONS

5.1 Mid-Air Collision

Two separate activities have been initiated to minimise the probability of mid-air collisions. These can generally be categorised as “Plan to Avoid” and “Detect to Avoid”.

5.1.1 Plan to Avoid

Initially a military web based planning tool that could be used to de-conflict traffic was envisaged. This was referred to as the Defence Aircraft Collision Avoidance Service (DACAS). JHC already used a similar service provided by BAE Systems known as the Centralised Aviation Data Service (CADS) which has now been adopted more widely to provide the capability originally envisaged from DACAS. A long term goal is to replace CADS with a more advanced tool; the Defence Aircrew Collision Avoidance Planning Tool (DACAPT) however this is unlikely to be achievable in the short term (initial indication is for implementation in late 2015). In the interim it is planned to replace CADS in the next few months with the Defence Aircrew Situational Information project (DASIP). There is no significant impact on the helicopter platform itself from the adoption of these systems and this work has been taken forward by the JHC. Reference to these systems is included here for completeness only.

5.1.2 Detect to Avoid

A number of collision avoidance systems have been evaluated, ranging from relatively cheap “off-the-shelf” products aimed at the glider and general aviation market, generally referred to as Portable Collision Avoidance Systems (PCAS), to more sophisticated systems requiring considerable integration into the helicopter.

Two PCAS were initially considered, as if suitable, they would clearly provide the desired “quick win”; these were the Power FLARM shown in Figure 6 and the similar Zaon XRX. Both are widely available at low cost (typically less than £2,000). The major difference between the two systems is that whereas the Zaon is totally passive, interrogating transponder emissions from aircraft in close proximity to trigger alerts, the Power FLARM is an active system. In addition to receiving transponder data the Power FLARM transmits its position to other Power FLARM units, this makes it very useful when fitted to non transponder equipped aircraft but does mean in a military context that the helicopters position is being broadcast on a non-secure system.

Figure 6: PowerFLARM (image courtesy of Butterfly Avionics Gmbh)

The PCAS do not require integration into the cockpits and can be considered as “carry-on” items from a clearance perspective. Enhancement of the systems can be achieved by the addition of external power supplies and aerials to improve sensitivity and they can both be used to feed external displays. A Power FLARM “Core” is available that has no display expressly for this purpose. For the evaluations carried out the two systems were used in a stand alone mode, as to integrate them with any of the test helicopters systems would introduce considerable cost and delays to the programme.

The trials demonstrated that the system provided a capability to detect conflicting traffic. However the capability of these small systems is inherently limited by the receiver technology and functionality in the core design.

There were concerns with the likely eventual performance of these systems within a complex military operating environment. The decision as to whether to proceed with integration of a PCAS therefore fell to a balance of the amount of mitigation likely to be provided (and for how long), against the potential impact of trying to run a short-term interim project for PCAS, alongside a project for a longer term collision avoidance capability. The judgement was taken that a focus on one longer term mitigation option would provide a better overall risk reduction approach.

A more complex example of a Traffic Avoidance System (TAS) is the Avidyne TAS 600 family. The systems actively interrogate other aircraft's transponders and display surrounding traffic on a compatible display system. The TAS uses two aerials mounted above and below the fuselage. These systems are considerably more expensive than the PCAS and need to be integrated into a platform (between £10,000 and £20,000 plus the cost of integration). This introduces a considerable engineering burden that effectively precludes the system providing a "quick win". The UK fixed wing training fleet has adopted a TAS solution following a number of mid-air collisions between military light aircraft in the past and the system is now established within the UK military fleet.

At the upper end of the spectrum are systems generally referred to as Traffic Collision Avoidance Systems (TCAS). These systems have the functionality of those previously described but in addition provide Resolution Advisory advice. The current standard system is TCAS II. These are widely used in the off-shore oil and gas support helicopter fleet and are mandatory for civil fixed wing operations.

Integration of TCAS II systems into some military helicopters is being considered as a long term solution.

5.2 Wire Strike

A number of different approaches have been considered to mitigate the risk of wire-strikes; these include the use of obstacle terrain databases, active detection systems and wire cutters.

5.2.1 Wire Avoidance and Detection

A possible solution that is currently being assessed is the use of a hand held (or knee mounted) tablet; see Figure 7, providing a suitable level of display to the crew. This is anticipated to be relatively straightforward to implement, being little more than an electronic version of the paper maps that are part of a helicopter pilot's "flight bag". However, while known wires are marked on the electronic maps, no warning is provided. Progress is being made in improving the marking of wires on paper maps.

Figure 7: An example of a Knee Mounted Tablet in use in the Apache Cockpit (image courtesy of Inzpire Ltd)

Enabling a tablet based solution to give a warning of approaching wires may lead to software certification issues. Whether these issues arise is a matter of whether the warning system is classed as advisory or as a system upon which the pilot depends. A system that a pilot is dependent on requires a much higher level of testing to prove that it is reliable, comprehensive, and has a very low false alarm rate. This increased complexity would add considerable expense to the implementation of the system.

5.2.1 Wire Cutters

The most widely fielded mitigation to wire strikes is the use of wire cutters. The first "modern" wire cutters started development in the late 1970s following a series of incidents. Magellan Aerospace is the world leader in developing these systems having acquired the rights to the original Wire Strike Protection System (WSPS) along with the manufacturer (Bristol Aerospace) some years ago.

The system consists of a series of cutters and deflectors fitted to the forward facing parts of the helicopter. For most civil helicopters, and some military ones, this is usually limited to a cutter assembly mounted above the cockpit, one below and a reinforced deflector on the windscreen structure. All of these features are discernable in Figure 8. For more complex systems a large number of additional deflectors are located at strategic locations to minimise the probability of an impacted cable snagging on external equipment. The Apache is a good example of this type of heavily engineered solution with deflectors on the undercarriage legs, sighting system and underslung 30mm cannon.

Any physical system will have a performance limitation which will be a combination of the speed of collision, the angle of impact and the size of the wire. Any testing to derive precise performance characteristics is likely to be complex, expensive and unable to cover all possible combinations of factors. Therefore, as with mitigation options for mid-air collisions and operation in DVE, there is a need to recognise that whilst the system will provide some protection, the exact level is unlikely to be quantifiable nor will it be absolute.

Figure 8: RAF Griffin HT.1 showing wire cutters mounted above and below the cockpit (circled) and deflector on windscreen support structure (arrowed) (image courtesy of www.defenceimages.mod.uk)

5.3 Operation in DVE

Helicopter landing operations in Degraded Visual Environments give rise to a number of challenges. In the hover and low speed envelope the pilot requires external visual cues to control attitude and position and when these cues are inadequate this can lead rapidly to spatial disorientation (SD) and loss of situational awareness (SA). SD can cause poor perception of fore/aft and lateral drift, rate of descent, ground speed and closure rate; loss of SA can result in reduced awareness of the landing surface such as the size, roughness, slope, obstacles and hazards. As a consequence, the helicopter might land in a manner which induces a degree of lateral momentum that could lead to loads in the undercarriage or primary structure which are beyond the design case, and subsequent structural damage. In more severe cases structural failures can result in aircraft roll over on contact with the ground or collision with nearby obstacles.

There are two basic ways to address this problem:

- Provide an improved visual cueing environment to overcome the loss of external visual cues and ensure the pilot can maintain control.
- Use an Automatic Flight Control System (AFCS) to improve the handling qualities limitations such that loss of visual cues is no longer hazardous.

Improved visual cueing can be achieved through the use of a sensor/synthetic vision system or through guidance symbology. Symbology can be divided into two different formats:

- 2-dimensional (2-D) fixed flight symbology providing instrument data around the periphery of the display supplemented by graphical information such as the US Army Brown Out Symbology System (BOSS)[6].
- 3-dimensional (3-D) perspective graphic symbology, which provides conformal (earth referenced) cues for the landing position, together with the ability to extract aircraft fore/aft, lateral and vertical closure rates from the differential motion between the cues. This approach was used in the UK Low Visibility Landing (LVL) research programme which was undertaken between 2008 and 2011[7]. Figure 9 gives an indication of the level of detail provided by the system.

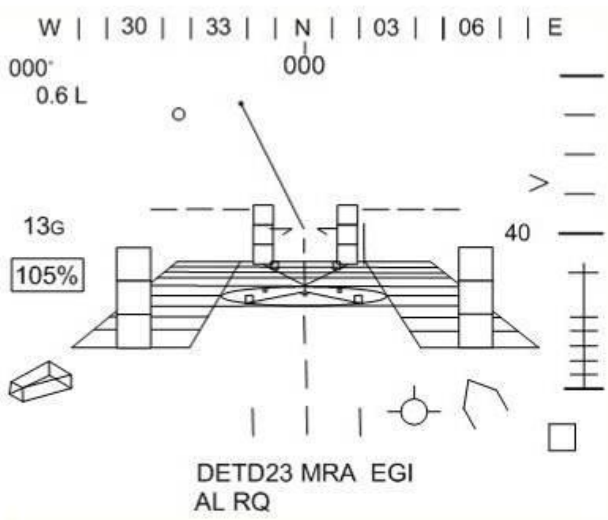

Figure 9: An example of 3D Conformal Symbology (image courtesy of Ferranti Technologies Ltd)

Either approach can provide acceptable cueing to allow safe control. However, although 2-D symbology has been highly developed, it results in a high pilot workload. 3-D symbology is a newer technology and although it is more complex to introduce, as it requires accurate helmet tracking, there is evidence that it results in a lower workload than 2-D approaches. Furthermore, 3-D conformal symbology presented on a helmet mounted display offers a new approach to cueing, which can be exploited to provide new means of cueing, guiding and informing military pilots for a wide range of tactical functions.

Sensor and Synthetic Vision Systems provide the pilot with an external view using information derived from a sensor (such as an EO/IR device, radar or lidar) combined with Digital Terrain and Elevation Data (DTED). These systems aim to allow the pilot to "see through" the degraded visual environment. It should be noted that mm wave radar offers the best solution for actually seeing through a dust cloud. Examples of candidate synthetic vision systems include:

- Sierra Nevada Corporation (SNC) Helicopter Autonomous Landing System (HALS).
- BAE Systems Brown-out Landing System (BLAST).
- Air Force Research Laboratory (AFRL) 3-Dimensional Landing Zone (3D LZ).
- CAE Advanced Vision System (AVS).
- Cassidian Helicopter Laser (HELLAS) Synthetic Vision System (SVS).

Work on these systems is currently ongoing with considerable resources being expended in their development. At the present time none of them can be considered sufficiently mature to deliver a fieldable solution.

Use of an automatic flight control system (AFCS) seeks to address the DVE problem by enhancing handling qualities such that loss of visual cues is no longer hazardous. An AFCS can be used in one of two ways - either by using an autopilot to fly the aircraft (automatic transition and automatic hovering), or through enhanced flight control which provides the pilot with a very stable yet highly manoeuvrable platform[8]. The advent of digital AFCS (DAFCS) has enabled enhanced flight control systems to be developed (e.g. the Chinook CH47F DAFCS) and has also enabled autopilot modes to be developed which include time as a controlling parameter (so-called 4-D control). Autopilot functions are typically designed to provide gentle manoeuvring so that the pilot perceives a predictable and repeatable flight path. Their use in automatic transitions tends to result in a slower approach to the hover than a pilot would normally fly tactically.

Each of these approaches addresses part of the DVE problem. An ideal solution would be a combination of symbology, flight control enhancements and sensing to eliminate the risk of operating in DVE. However the value for money of adopting such a solution would need to be determined through cost benefit analysis on each platform independently along with the practicalities of introducing these technologies on a case by case basis. In addition, the use of EO/IR devices offers a mature technology for surveying the suitability of the landing zone from distance to allow early obstacle detection prior to brown-out/white-out but is ineffective once a dust or snow cloud develops. Radar systems based on mm wave technologies provide a viable solution to see through the dust cloud, however candidate systems are currently only at a developmental level.

A key challenge with all such technologies is developing the system integrity to a level which will allow regulatory authorities to approve their use so that they can be relied upon to reduce the risk rather than increase it.

6. CASE STUDY

Figure 10: RAF Griffin HAR.2 (image courtesy of www.defenceimages.mod.uk)

84 squadron, RAF based at Akrotiri, Cyprus operates four Griffin HAR.2 helicopters which are derived from the Bell 412EP see Figure 10. The Griffin is used for Search and Rescue (SAR) duties over land in mountainous terrain during the day and over the sea at night using night vision goggles and a FLIR/TV turret. The Squadron's primary role is the rescue of downed aircrew in the water or on cliffs, and the rescue of personnel from military and

commercial shipping. The helicopters are supplied and maintained by the civilian company FB Heliservices, but are operated by military aircrews.

Analysis indicated that the benefit of providing these helicopters with the capability to operate in DVE was limited and did not warrant further investment at this time. The analysis did suggest that providing mitigations against mid-air collisions and wire strikes was beneficial and should be pursued.

6.1 Mid-Air Collision Avoidance

A number of options were considered to provide a mid-air collision avoidance system for the UK helicopter fleet. The favoured solution for a large number of types is the Avidyne TAS 615; amongst the earliest of our platforms to be so equipped through this programme will be the Griffin HAR.2.
The majority of UK military helicopters are equipped with Honeywell Multi Function Displays (MFD) with which the TAS system can be integrated. Unfortunately this was not an option for the Griffin and following a short assessment phase the Avidyne EX600 MFD was selected for this helicopter; Figure 11 shows an indicative TAS display on this MFD.

Modification of the aircraft has been contracted to FB Heliservices with installation on the first aircraft planned for early 2014.

Figure 11: Typical display from Avidyne TAS 615 on EX600 Multi Function Display (image courtesy of Avidyne Corporation)

6.2 Wire Strike Mitigation

The Griffin HAR.2 is to be fitted with the Magellan Aerospace WSPS over the coming months. The RAF operates a fleet of similar helicopters in the training role which are already fitted with top and bottom cutters, illustrated previously in Figure 8.

The design of the cutter fit for the Griffin HAR.2 will be based upon the earlier design but has to take into account the various additional pieces of equipment fitted to the exterior of the helicopter. Work is currently underway to equip the first helicopter including the verification of the integrity of the structure to withstand the loads associated with wire strikes which is being addressed at the same time.

7. CONCLUSIONS

The UK has recognised that the operating risk associated with military helicopters is significant; an experience that appears to be shared with, and documented by, other military users. The Helicopter Safety Enhancement Programme is addressing this risk to life to enable UK Duty Holders to deliver their personal, legal responsibility to effectively manage air safety on their platforms. The programme has identified upwards of 30 potential safety enhancements and, by using the Cost Benefit Analysis approach described in the paper, is prioritising these. Leverage (particularly relating to re-use of existing detail design) can be obtained from existing civil equipment where, in some instances progression has allowed quick win solutions to be engineered and fitted to helicopters.

7.1 Mid-Air Collision Avoidance

The UK MOD is actively considering installing systems on the majority of the helicopter fleet. For most types the decision in the short term is to fit a non-integrated system, most likely to be a TAS type unit. For the larger platforms (Chinook, Merlin and Puma) the fitment of fully integrated TCAS II systems is being considered.

7.2 Wire Strike Avoidance/Mitigation

A number of UK MOD helicopters already have a comprehensive fit of wire cutters, including Apache, Merlin Mk.3 and Wildcat. The programme is aiming to role out a similar capability across the majority of the remainder of the fleet with one or two exceptions where suitable wire cutter installations are not available.

There is currently no wire cutter kit developed for the Chinook and there are no known plans to develop one. The cost and timescale associated with introducing this capability suggest that an alternative means of protecting the aircraft against wire strike may be a better option. Assessment of a tablet based moving map capability is underway, which would have details of known wires and obstacles overlaid. The key to this type of system is considered to be an effective means of alerting the aircrew to the presence of wires without them having to spend prolonged periods “eyes-in”.

7.3 Operation in DVE

Perhaps the greatest challenge from a safety enhancement perspective is to introduce a robust means of operating in DVE. Considerable effort has been invested in developing a solution over the past 5 years. The UK MOD research programme took 3D Conformal Symbology to a level where it was demonstrated in flight trials and within a simulator environment, but there is significant investment required to field this as a reliable system that is certified as suitable for in-service operation. The programme has considered a number of alternative "vision" type systems (mm wave radar appearing to provide the best option) however these are considered as being at a developmental level and some way from providing a fieldable solution at this time. There is some evidence that the use of a Digital Automatic Flight Control System (DAFCS) with higher order autopilot modes can provide a beneficial level of mitigation.

The UK is currently in the process of procuring a new batch of 14 Chinook helicopters that are closely related to the CH-47F in service with the US Army. These will be equipped with a highly capable DAFCS which will enhance flying qualities significantly in DVE providing some mitigation.

Options are currently being explored for the legacy Chinook fleet, Merlin and Puma. DAFCS solutions are under consideration where they offer an early solution. The UK MOD is in addition exploring the cost/benefit of productionising a 3D Conformal Symbology solution for initial implementation on Merlin.

8. REFERENCES

[1]. wikipedea.org/wiki/List_of_active_United_Kingdom_military_aircraft downloaded 8th July 2013

[2]. Haddon-Cave, C, The Nimrod Review, HMSO 28th October 2009

[3]. Anon. MAA Regulatory Article 1020 Issue 2, RA1020 – Roles & Responsibilities: Aviation Duty Holder (DH) and DH-Facing Organisations, downloaded 17th June 2013.

[4]. Couch, M.; Lindell, D, Study on Rotorcraft Safety and Survivability; presented at the American Helicopter Society 66th Annual Forum, Phoenix, Az, 11th -13th May 2010.

[5]. Anon. MAA/RN/12/11 (DG) – Cost Benefit Analysis of Potential Air Safety Measures – Principles, 8th November 2011.

[6]. Szoboszlay, Z.P.; Turpin, T.S.; McKinley, A.R. Symbology for Brown-Out Landings: The First Simulation for the 3D-LZ Program; presented at the American Helicopter Society 65th Annual Forum, Grapevine, TX, 27th - 29th May, 2009.

[7]. Goff, C.P., Ball, A.N., Yapp, J.L., Pearce, S.J. and Crawford, F.L. Developing a 3D Landing Symbology Solution for Brownout; presented at the American Helicopter Society 66th Annual Forum, Phoenix, Az, 11th -13th May 2010.

[8]. Padfield, G.D, Rotorcraft handling Quality Engineering, 32nd AHS Nikolsky Honorarary Lecture; presented at the American Helicopter Society 68th Annual Forum, Fort Worth, Tx, 1st -3rd May 2012.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of colleagues within the Helicopters Operating Centre of DE&S, Joint Helicopter Command, Military Aviation Authority, RAF Flight Safety and Dstl in the preparation of this paper. In addition the authors would like to acknowledge the assistance of a number of companies for provision of images used in this paper; these are credited individually as appropriate.