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# INVESTIGATION AND REVIEW OF HELICOPTER ACCIDENTS INVOLVING SURFACE COLLISION

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# INVESTIGATION AND REVIEW OF HELICOPTER ACCIDENTS INVOLVING SURFACE COLLISION

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# Foreword

The research reported in this paper was commissioned and funded by the Safety Regulation Group (SRG) of the UK Civil Aviation Authority and was carried out by GKN Westland Helicopters Limited and GEC Marconi Avionics Limited.

Safety Recommendation 93–24, of the Air Accidents Investigation Branch (AAIB) Aircraft Accident Report 2/93 (accident to Super Puma, G-TIGH, near the Cormorant 'A' platform, East Shetland Basin, on 14 March 1992) recommended that the CAA should investigate the possibility of raising the current height of 100ft 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. However, it was agreed that research should be conducted to establish the nature and extent of the problem of helicopter surface collisions and to examine the case for the provision of a more effective and discriminating warning system.

To achieve these objectives, 30 helicopter accidents or incidents in which fully serviceable helicopters either flew into the sea or ground, or came close to doing so, were extensively analysed and all relevant information incorporated into an accident/incident database. This database was then used to determine what equipment, either currently available, or likely to be available in the near future, would have been of benefit in avoiding the occurrences.

In addition, by applying a set of formal rules to the information contained within the database, the particular problems that contributed to each occurrence have been identified and the functional requirements of a future system, or combination of systems, intended to help prevent such accidents/incidents occurring in the future, have been defined.

The database is the property of SRG and can be added to in the future.

Further development of this research, such as an assessment of the practicality and ease of implementation of each proposed solution in terms of availability, cost, weight etc, will be considered.

The work has been reported in two volumes.

Volume 1 (this volume) contains the main report, detailing the work undertaken and the results and conclusions.

Volume 2 contains the appendices to the main report (Volume 1) and includes all database information (at the time of publication), together with full tables of all the data produced in support of the work.

Safety Regulation Group

## Executive Summary


The number of occurrences in which fully functional helicopters either fly into the sea or ground, or come close to doing so, are a major cause of concern. In the two million helicopter flying hours carried out in the UK between 1976 and 1993 there have been 41 fatalities resulting from 9 such accidents.

A preliminary review of UK and foreign helicopter accidents involving surface collision, carried out by the Civil Aviation Authority (CAA), concluded that there is a significant problem and that further, more comprehensive investigation was necessary.

GKN Westland Helicopters and GEC Marconi Avionics have jointly undertaken a study in response to this requirement, in which 30 such accidents/incidents were analysed and the details entered into a database. A review of this database revealed that, out of the 30 cases considered in this study:

- Twenty six occurred during visual contact flight and, in all but one of these, cues from one or more aspects of the external environment were either degraded in quality in some way, or were non-existent. Lack of horizon cues, flight over surfaces with no cues (such as glassy water) and misleading feature cues appear to engender particular difficulty in maintaining spatial awareness and orientation.
- Insufficient instrument monitoring was judged to be a factor in 26 cases with lack of awareness of both altitude and rate of descent being critical.
- Crew workload was found to be high in 13 cases.
- Inadequate procedures, or failure to correctly follow procedures, were a factor in 15 cases.
- Of the 15 cases with 2 flight crew, poor crew interaction was significant in 9 cases, and possibly contributory in a further 4.

The assessment of each case included a judgement of the benefit of particular equipment, either currently available, or shortly to become available, to prevent the circumstances of each case if that equipment had been fitted and used correctly.

Radio altimeter information was judged to have the potential to help in 23 cases. However, as these were fitted to the majority of helicopters considered, this indicates a problem with awareness of either the absolute altitude, or its significance relative to the terrain. Compelling height warnings, and the Automatic Voice Alerting Device (AVAD) were deemed of benefit in the majority of cases.

Further systems judged to have the potential to prevent some of the accidents/incidents considered were a radio altimeter height hold autopilot mode, ground proximity warning system, flight path warning system (which warns of an unreasonable combination of flight parameters) and approach aids. The approach aids would have helped in 11 of the 12 cases which occurred during the approach and landing phases of flight.

In addition to this subjective assessment of available equipment, a task was carried out to define the functional requirements of future systems. This study derived the problems that contributed to the occurrence from the database record of each accident/incident, via a series of formal rules. This led directly to a set of functional requirements for a system that

either prevented, or circumvented, these contributing factors. The top 10 problems, in order of decreasing number of occurrences, were:

- Insufficient instrument monitoring
- Lack of awareness of rate of descent
- Lack of awareness of altitude
- Poor external horizon cues
- Excess external monitoring
- Poor visibility
- Poor textural cues
- High workload
- Crew interaction problems
- Poor procedures

However, a system that addressed all of these issues, although ideal, could prove complex and difficult to implement. Thus a series of individual solutions were considered for their suitability in solving the identified problems.

An intelligent flight path monitor, which considers both the aircraft's state and its position relative to the outside world, was the best potential solution (i.e. it addressed most problems) in 16 of the 30 cases. Automatic Flight Path Control was deemed to be the best solution for 4 cases with the remaining 10 being best addressed by adoption of a simple helmet with head tracking to include horizon display. These solutions were the only 3 out of the 71 proposed that were judged best solutions for individual cases.

By considering all problems for all cases, the intelligent flight path monitor addressed 44% of all problems with the simple helmet comprising a horizon line display addressing 35%. Applying these 2 technologies together was found to address 77% of all problems across the 30 cases. On a case by case basis this pairing also proved the best combination in 22 of the 30 cases considered.

## Contents (Volume 1)

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## Contents Appendices (Volume 2)

# 1 INTRODUCTION

## 1.1 General

This two volume document reports on an investigation and review of helicopter accidents involving surface collision. It constitutes the final report of the study carried out by GKN Westland Helicopters and GEC Marconi Avionics for and on behalf of the Civil Aviation Authority's Safety Regulation Group (Reference 1).

## 1.2 Background

In 1992, an AS 332L Super Puma helicopter crashed into the sea en-route from the Cormorant 'A' production platform to the Safe Supporter, a 'Flotel' just 200 metres away. The helicopter 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 (Reference 2) found that the loss of the aircraft and the associated fatalities and injuries were due to a combination of factors:

(i) Failure of the pilot to recognise the rapidly changing airspeed/groundspeed relationship caused by turning downwind.

(ii) The pilot allowed the airspeed and height to decrease whilst turning away from a strong, gusting wind.

(iii) The inability of the helicopter to arrest the descent, despite the application of full power, in the height available when the pilot became aware of the descent.

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.

One of the Air Accident Investigation Branch (AAIB) recommendations arising from the accident was that the CAA should investigate the possibility of raising the height (100ft) 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 to:

- establish the nature and extent of the problem of helicopter surface collisions.
- examine the case for the provision of a more effective and discriminating warning system.

The number of occurrences in which fully functional helicopters either fly into the sea or ground, or come close to doing so, are a source of major concern to the CAA. In the two million helicopter flying hours carried out in the UK between 1976 and 1993 there have been 41 fatalities resulting from 9 such accidents. In view of this, the CAA formulated a research programme to investigate surface collision which embodied the AAIB recommendations and the views expressed by operators.

This research programme was initiated by conducting a limited survey of accident and incident data from the UK and overseas. The findings of this initial research have defined the objectives of this project which are:

(a) To carry out a broader survey of accidents and incidents and examine each in greater depth.

(b) To investigate whether currently available equipment could have prevented identified accidents and incidents.

(c) To identify any common features or characteristics of surface collision accidents/incidents.

(d) To recommend the functional requirements of a system capable of preventing surface collision accidents.

## 1.3 Surface Collision Accidents

While each aviation accident has its own unique circumstances, the Cormorant 'A' 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 this type of accident difficult to prevent. Whereas significant progress has been made in the reduction of aviation accidents caused by mechanical or avionic system failures, 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.

## 1.4 Tackling the Problem

Attempts have been made over the years to help the crew avoid surface collisions, often referred to as Controlled Flight into Terrain (CFIT) accidents in fixed-wing circles. The AVAD, which was installed in the Cormorant 'A' helicopter, and the Ground Proximity Warning System (GPWS) installed in many fixed-wing aircraft, are examples of systems that have been developed to help the crew. These systems have their limitations, as the Cormorant 'A' accident demonstrated. Matching their performance to a wide range of operational circumstances to produce a useful warning without a high frequency of false alarms is difficult.

Recent technology developments provide the basis for more sophisticated systems that could address the problem. These include systems that use the most modern navigation and display equipment to provide greater crew situational awareness and intelligent systems that model ideal pilot behaviour and warn of crew actions that deviate significantly from this reference model. Research has tended to concentrate on fixed-wing aircraft applications, partly because of the predominance of fixed-wing operations but possibly also because the helicopter case is more difficult to tackle for the following reasons:

- helicopter operations are less rigidly defined and include take-offs and landings away from sophisticated bases.

- helicopters have additional degrees of freedom which make it more difficult to analyse vehicle behaviour and relate it to pilot intentions.
- providing helicopter pilots with the necessary situational awareness is more difficult.

## 1.5 Study Format

To achieve the objective of this project a 4 stage study has been completed.

*Stage 1 – Data Search and Collection*

Worldwide and national accident and incident databases were searched for records of accidents and incidents in which fully serviceable helicopters either flew into the sea or ground, or came close to doing so. Only reports from the following countries were considered:

(a) UK

(b) JAA member states other than the UK

(c) Australia, Canada and the USA

This resulted in 65 cases of interest being identified such that full accident reports could be requested from the relevant national authority. From the reports subsequently provided to the study team 30 cases were selected for further analysis.

*Stage 2 – Accident/Incident Review*

Each of the 30 chosen accident/incident reports was analysed and all aspects relevant to the study, whether factual or reasonably surmised, were placed in a database.

This database was developed specifically for this study and was designed to provide both a concise record of the accidents/incidents and a formal standard of data that could be accessed for subsequent analysis.

The database included the following sections:

- An introduction detailing the background and basic facts relating to the incident.
- Details of meteorological situation at the time of the occurrence.
- Assessment of the visibility and quality of external visual cues.
- A section outlining the workload, capabilities and interaction of the crew.
- Details of the autopilot, warning and instrument fit on the helicopter and any associated problems.
- Tabulation of relevant flight parameters at the critical point of the flight.
- An assessment of whether the crew did have, or could have had, knowledge of these parameters.

*Stage 3 – Examination of the Use of Equipment That is Either Currently Available or Could Soon be Made Available*

This database centred task assessed for each accident/incident a range of equipment for the following:

(a) The availability on the aircraft, at the time of the accident/incident, of equipment that could have assisted in the avoidance of the surface collision.

(b) The manner in which the equipment was used, if it was available.

(c) Whether the use of the equipment was beneficial, if it was available, or could have been of benefit if it had been fitted, in cases where it was not available.

*Stage 4 – Definition of Future Systems Functional Requirements*

The database generated in Stage 2 was analysed, using a series of formal rules, to identify the problems that existed in each of the accidents/incidents such that a means of avoiding, or circumventing these problems could be identified. These actions led directly to the identification of requirements for future systems, (as opposed to the currently available systems assessed in Stage 3), that aim to prevent helicopter surface collisions.

However, any single system, although ideal, could prove to be complex and difficult to implement. Thus a series of individual solutions were addressed for their suitability in solving the identified problems, both individually and in pairs with other solutions. This led to the identification of the solution, or pair of solutions, that was most effective either for each case or overall.

## 1.6 Report Format

The report is divided into two volumes, Volume 1 includes the main body of the text (Sections 1 to 8), whilst Volume 2 contains the appendices.

Section 2 outlines the means of identifying relevant cases, collection of accident reports and selection of the best 30 cases;

Section 3 describes development of a database such that all relevant aspects of each of the accidents/incidents could be recorded in a single concise format;

Section 4 summarises the potential benefit of equipment that is either available, or could soon be made available, in preventing such occurrences;

Section 5 details the means of identifying the functional requirements of future solutions to prevent helicopter surface collision occurrences;

Section 6 summarises the report's findings;

Section 7 lists the references cited in the text;

Section 8 lists the acronyms used in the text;

Appendix A is the accident/incident database.

Appendix B is the glossary for the accident/incident database.

Appendix C is the preventative equipment database.

Appendix D is the glossary for the preventative equipment database.

Appendix E is the Table of Problem Aspects.

Appendix F lists Future System Requirements for each case.

Appendix G is the Table of Potential Solutions.

Appendix H lists the Most Effective Single Solutions for Each Case.

Appendix I lists the Most Effective Combined Solutions for Each Case.

# 2 IDENTIFICATION OF CASES TO BE INVESTIGATED

## 2.1 Data Search and Collection

In order to select 30 cases of helicopter accidents/incidents for detailed analysis it was first necessary to search for all applicable cases from which to make a selection.

The data search, in accordance with the requirements of the proposal, for accidents and incidents of IFR certificated helicopters began by obtaining the helicopter section of the 'World Airline Accident Summary' (WAAS), 1965 to mid 1995 (Reference 3).

A manual search through each case within this document, discounting accidents due to aircraft and system failure or unservicability, identified 198 cases that were potentially of interest.

Of these, 73 accident cases of all types of surface collision were outside of the country classification of the contract i.e. not within:

(a) The UK;

(b) JAA member states other than UK;

(c) Australia, Canada and USA.

Eighty four of the accidents identified are within these countries of interest but involved light helicopters, wire strikes and non-professional operations (typically Visual Flight Rules (VFR) operations involving inadvertent flight into Instrument Meteorological Conditions (IMC)) and, as such, are outside the scope of the study. Therefore the remaining 41 accidents qualified as being correct in type of accident and country and became the first 41 cases of the study.

Initially, it was the intention to include only those accidents/incidents involving Instrument Flight Rules (IFR) certificated helicopters. In practice it proved difficult to ascertain this information. In addition, there was a lack of information as to whether the pilot was instrument rated and whether the helicopter was being flown under IFR at the time of the accident/incident. Consequently, the criteria was amended and cases were selected on the basis of the helicopter being twin engined and professionally operated.

The next stage of the search was to identify the incidents, as opposed to accidents in which personal injury or aircraft damage was sustained, which were potentially of interest. This was carried out initially by obtaining a computer database run for the UK from the CAA Mandatary Occurrence Reporting (MOR) system. This was done using the keyword 'human factors' and this gave 280 records of both accidents and incidents. This procedure added a further 2 cases of interest to those established from the WAAS search.

Identifying incidents for the countries other than UK was carried out by requesting database runs from the International Civil Aviation Organisation (ICAO) Accident Data Reporting and Entry Procedure (ADREP) system of accident/incident recording.

The first run request used the keywords '1st event collision' and gave 271 cases. Close consideration of each of these gave 19 cases to be included in the study. A second ICAO run was then requested using the keywords 'pilot disorientation/distraction'. This data run gave 8 additional cases of which none were considered suitable for inclusion in the study.

The identification procedure had produced 62 cases for the study with an additional 3 cases identified by the CAA. These 65 cases were reviewed using the narrative summary and given an interest ranking, one (high) to 10 (low) according to the applicability of the incident/accident to the study and quality of information available.

The philosophy for report collection and subsequent selection of cases to be investigated, was to request all 65 accident reports and use the highest ranked reports that were returned by a deadline date.

Report collection was carried out by contacting the relevant Airworthiness Authority for each country and requesting full accident investigation reports.

The quality of the reports reviewed varied depending on the country of origin. UK reports obtained from the Air Accident Investigation Branch were of a high quality and amongst the best received. Others varied from 2 page summary reports to 'factual files' supplied by the National Transportation Safety Board of the USA. These factual files contained such items as a narrative summary, pilots and co-pilots reports and some discussion. There was no in depth analysis or conclusions. However, no further information was available and an informed interpretation of these cases was necessary.

Full accident reports exist for the two Australian and one of the Canadian cases. Full reports exist for the German, Scandinavian and Spanish cases but these are in the language of those countries and not available for ready analysis. It may be appropriate at a later date to translate these and add to the number of cases covered by the study.

### 2.2 Selection of Cases to be Investigated

The cases for which reports were available were carefully examined for possible inclusion as one of the final 30 cases to be given full analysis.

The highest ranking of cases for inclusion was on consideration of each of the following factors:

- Ideally IFR certificated, if not, ideally twin engine.
- Professionally operated.
- Transport category operation.
- Well equipped (IFR) package.
- Full in-depth accident report available.

With more detailed information available, a number of cases were excluded by a joint decision of the study team by virtue of a low interest ranking, for example due to collision with obstacles whilst in low level manoeuvring flight, or poor professional judgement by the pilots.

The final 30 cases used had an interest ranking of 8 or higher. They 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.

It should be noted, when considering the further analyses in this study, that the batch sample size of thirty is small, with the cases selectively chosen from a large number of accidents and incidents. With the information available to the study team being limited, particularly the level of detail in some reports, it would not have been possible to enlarge the sample size without translating foreign language reports.

## 3 ACCIDENT/INCIDENT REVIEW

### 3.1 Objectives

Two objectives were identified for the review of the accidents/incidents selected for use within this study. Firstly a means had to be found for recording the information obtained from the reports, in a manner that was concise and capable of being analysed further using standard database query techniques. Secondly, it was required to record the detailed descriptive information gathered from the reports for later retrieval by other users of the database. For both applications, the database would have to encompass such areas as: general details of the flight; a record of the weather conditions and visibility; crew workload breakdown and a description of the flightpath at the critical time within the flight.

The study team was also required to perform an analysis which would identify whether currently available equipment, if fitted and used in the correct manner, would have been of benefit in each of the situations reviewed.

### 3.2 Database Design

In order to start the database design process, a single record was produced for a selected accident. This included a number of fields to contain information covering each of the topics which it was considered required review. This preliminary database was used as the basis for discussion within the study team and with the CAA. As a result of these discussions, fields were added and modifications were made in order to arrive at the final form described below. A listing of the information stored in the database along with a glossary describing each field is presented in Volume 2 of this report.

In the database, memo fields were used to hold descriptive information whilst other aspects of the review were performed using numeric fields, simple yes/no fields, or fields which required a single word reply from a multiple choice of answers.

The final form of the database consisted of:

(a) 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. One memo field was provided to allow a summary of the occurrence to be included (usually obtained directly from the report), whilst another memo field was provided to enable the comments appropriate to the study to be added.

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

(c) 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.

(d) 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.

(e) 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.

(f) 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. Such items as aircraft pitch, heading and rate of descent were recorded along with an assessment of whether the crew did, or could have had, knowledge of each of these flight parameters.

A separate database was provided to enable the review of current and soon to be available means of accident/incident prevention to be carried out. This database consisted of a memo field for some descriptive text, followed by a listing of each of the accident/incident prevention means. Fields were provided to establish whether the equipment was available on the aircraft, whether it was used and in what manner. Finally an assessment was made as to whether the system would have been of benefit if used. A full listing of this database and its associated glossary is provided in Volume 2 of this report.

### 3.3 Review Procedure

The 30 accidents/incidents were reviewed in order of decreasing interest ranking. Each report was assigned to a member of the team who would extract the relevant information and enter it into the database. This entry was then checked for accuracy and consistency by another member of the team. Once any mutually agreed changes had been implemented, an issue number and date were assigned to the record, in order to track any changes made to the entry after this stage. A number of reports with high priority ratings were also passed, along with a listing of their database entries, to the GKN Westland helicopter test pilot associated with this project for his analysis and comments. Accident reports containing Cockpit Voice Recorder (CVR) and Flight Data Recorder (FDR) data were easier to analyse than those without this information.

## 3.4 Results

Upon completion of the review procedure, two databases had been produced which were used to provide the basic information required for subsequent analyses. The accident/incident database was used to provide information for the definition of future system functional requirements. This database is included in Volume 2 as Appendix A with a glossary of the fields as Appendix B. The review of the use of available equipment database (Appendix C – glossary Appendix D) could be interrogated directly, using standard query techniques, to establish some statistics with regard to the benefits of currently available equipment.

Some broad observations can be derived from an initial examination of the data. This investigation is presented in the following sections.

### 3.4.1 *General Details*

An examination of the general details of the cases revealed the following:

Twenty six of the 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. The high number of over water occurrences may reflect not only the relative proportion of the total usage of helicopters that is devoted to over water operations, but also the poor visual cues provided by water surfaces in some circumstances.

### 3.4.2 *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 accident/incident reports stated that 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. Examples, extracted from the reports, of these shortfalls in the Operating Manuals are:

- Insufficiently detailed procedures for approaches in poor visibility.
- No procedures for the use of AVAD during visual approaches.
- No rules for assessing risks for Search and Rescue Missions in poor conditions.
- Poor manual layout leading to confusion as to the Non-Handling Pilot's role.
- No procedures for recovery from loss of airspeed.
- No procedures for transitioning from the hover to forward flight on instruments alone.
- Poor coverage of night visual approaches.
- No guidance on the use of the Radio Altimeter in poor visual conditions.
- No approach procedures for blowing snow conditions.

This list indicates that there is still scope to improve safety through analysis of the operational procedures.

### 3.4.3 *Weather and Visibility*

Poor visibility appears to have played an important part in many of the occurrences. Table 3-1 below summarises aspects of the visibility for the thirty cases.

**Table 3-1 Summary of Available Visual Cues for the 30 Cases**

| | *None* | *Degraded* | *Misleading* | *Good* | *Not Known* |
|---|---|---|---|---|---|
| External Cues | 6 | 21 | | 3 | |
| Terrain Cues | 9 | 18 | | 3 | |
| Surface Cues | 9 | 19 | | 2 | |
| Horizon Cues | 19 | 7 | | 2 | 2 |
| Feature Cues | 9 | 12 | 7 | 1 | 1 |

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.

### 3.4.4 *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 (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, e.g. 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 the 8 cases investigated, where lack of knowledge of pitch attitude was a factor, 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. In 4 of the 8 cases where lack of knowledge of pitch attitude was a factor the crew had a completely wrong impression of the value of this parameter.

In all 8 cases where lack of knowledge of airspeed was a factor in the occurrence, the final critical airspeed was below 40kt, 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 groundspeed 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.

## 4 EXAMINATION OF USE OF EQUIPMENT THAT IS EITHER CURRENTLY AVAILABLE OR COULD SOON BE MADE AVAILABLE

### 4.1 Objective

One of the objectives for the study was to identify items of equipment that are currently available, or could soon be made available, that if installed and used correctly have the potential to avoid surface collision incidents. To achieve this, a database was created to store information regarding the use of available equipment. For each of the thirty cases this recorded:

(a) The availability on the aircraft, at the time of the accident, of equipment that could have assisted in the avoidance of the surface collision occurrence.

(b) The manner of the use of the equipment, if it was available.

(c) Whether the use of the equipment was beneficial, if it was available, or, in cases where it was not available, whether it could have been of benefit if it had been fitted.

### 4.2 Selection of Equipment

Before the start of the study it was envisaged that the following list of equipment would be investigated.

- Radio Altimeter
- Autopilot Functions
  - Radio Altimeter Hold
  - Heading Hold
  - Airspeed Hold
  - Turn Co-ordination
- Low Height Warning Repeaters Fitted to Central Warning Panel
- AVAD
- Flight Path Warning
- Ground Speed and Drift Indicator

Through subsequent discussions the list of equipment to be analysed was expanded to also include the following:

- Hover Hold Autopilot Mode
- Auto-Transition Autopilot Mode
- Ground Collision Avoidance System

- Weather Radar
- Obstacle Avoidance System
- Improved ATC Facilities
- Approach Aids
- Improved Displays

## 4.3 Function of Equipment

The following functionality was assumed for each of the systems listed above. All systems are currently available except where specified.

### 4.3.1 *Radio Altimeter*

The standard radio altimeter device whereby height is gauged by measuring the time required for a radio beam, projected at the surface by an aircraft mounted transmitter, to reflect to a receiver mounted on the aircraft. In this implementation the height is presented on a dial and/or digital display. Generally two Decision Height (DH) visual warnings are provided, one operating at a fixed height (usually 100ft for the cases examined, but now set to a mandatory 150ft in the UK), the other operating at a bug selectable height. This second warning is a non-mandatory customer option.

### 4.3.2 *Radio Altimeter Height Hold Autopilot Mode*

This autopilot mode maintains height above the surface by use of a radio altimeter system.

### 4.3.3 *Heading Hold Autopilot Mode*

This autopilot mode receives inputs from the aircraft's heading reference system in order to maintain a given heading.

### 4.3.4 *Airspeed Hold Autopilot Mode*

Inputs from the aircraft's air data system are used to maintain airspeed in this autopilot mode.

### 4.3.5 *Hover Hold Autopilot Mode*

This autopilot mode is used to maintain a stable hover. Inputs from an inertial system are used to maintain the correct attitude, whilst velocity measurements from a doppler radar or an inertial system are used to maintain a constant position.

### 4.3.6 *Turn Co-ordination Autopilot Mode*

In order to achieve a co-ordinated turn this autopilot mode maintains the correct relationship between the cyclic and yaw control to ensure that no sideslip occurs.

4.3.7 *Auto-Transition Autopilot Mode*

This autopilot mode provides the combination of cyclic, collective and pedal inputs required to ensure the correct relationship between aircraft pitch and speed in order to produce a safe transition to and from the hover.

4.3.8 *Low Height Warning System*

This category encompasses any improvement to the current standard of radio altimeter to make the visual DH indication more compelling. These improvements could range from improving the visibility of the standard indication in it's normal position, to moving the indication to a more prominent position on the central warning panel.

4.3.9 *Automatic Voice Alerting Device*

This device provides audio voice warnings when certain parameters have passed a preset value. Currently the most common application is to provide warnings when the aircraft descends below the decision heights set on the radio altimeter.

4.3.10 *Ground Proximity Warning System (GPWS)*

The GPWS is designed to prevent controlled flight into terrain, by giving the flight deck crew advanced warning both audibly and visually, of an unsafe flight condition close to the ground. The system is designed to alert the crew in any of the following circumstances: if an excessive descent rate is observed; if an excessive terrain closure rate is observed; if a loss of altitude occurs after take-off or following an overshoot; if unsafe terrain clearance occurs, and the aircraft is not in the landing configuration; if the aircraft departs too far below the glidepath during an ILS approach.

The GPWS receives inputs from the radio altimeter, the ILS glidepath receiver, a vertical speed sensor (which may be a barometric altimeter, the output of which is integrated by the GPWS to derive vertical speed) and a switch which is activated by the landing gear. Current systems are optimised for fixed wing aircraft operation.

4.3.11 *Flight Path Warning System*

This device warns the pilot that the aircraft has, or is approaching, an unreasonable combination of flight path parameters, (e.g. low airspeed combined with high rate of descent, low airspeed combined with high nose up attitude and low power). Flight path warning systems are not currently available but could gain the necessary information from existing sensors and systems within the aircraft, such as the air data system and the inertial system.

4.3.12 *Ground Speed and Drift Indicator*

This system uses Doppler radar to provide an indication of the speed of the aircraft over the surface in both the longitudinal and lateral directions.

#### 4.3.13 *Weather Radar*

This category encompasses the function of using a radar to determine the weather conditions en-route. It does not include the obstacle and object detection capabilities of the radar.

#### 4.3.14 *Obstacle Avoidance System*

Any system or device that is capable of detecting obstacles in the long to medium range path of the aircraft, this includes the obstacle and object detection capability of the weather radar.

#### 4.3.15 *ATC Facilities*

Any provision of Air Traffic Control facilities that can direct or advise the crew of the aircraft during the course of the flight.

#### 4.3.16 *Approach Aids*

Any system or device that can provide assistance to the helicopter crew during the approach and landing phase of the flight, especially for use on offshore rigs.

#### 4.3.17 *Improved Displays*

This category includes any display that is an improvement upon the electro-mechanical displays that are still used on much of the North Sea fleet. These could range from, ad hoc replacements for some of the more problematical instruments, through Electronic Flight Instrument Systems, to Head Up or Helmet Mounted Displays.

### 4.4 Method

The majority of the statistical information regarding the use of currently available or soon to be available equipment was derived using standard query techniques on the equipment database.

### 4.5 Results

Table 4-1 below shows the number of cases in which it was judged that the equipments listed would have been of benefit, if fitted and used correctly, in avoiding the occurrences. Due to the paucity of information available in many of the reports, the number of cases for which the equipment was available, or used, could not be derived.

However it can be stated that in 10 out of the 12 cases where radio altimeter information was known to be available it was used in a sub-optimum manner. Similarly in all 4 cases where AVAD was known to be available it was used in a sub-optimum way.

**Table 4–1 Number of the 30 Cases Where the Use of Currently or Soon to be Made Available Equipment Would Have Been of Benefit in Helping to Prevent the Accident/Incident if Fitted and Used Correctly**

| Equipment | Number of Cases to Benefit (Out of 30) |
|---|---|
| Radio Altimeter | 23 |
| Improved Displays | 23 |
| Automatic Voice Alerting Device | 22 |
| Low Height Warning | 21 |
| Radio Altimeter Height Hold Autopilot Mode | 16 |
| Ground Proximity Warning System | 13 |
| Flight Path Warning System | 11 |
| Approach Aid | 11 |
| Airspeed Hold Autopilot Mode | 8 |
| Turn Co-ordination Autopilot Mode | 7 |
| Air Traffic Control | 5 |
| Obstacle Avoidance System | 3 |
| Ground Speed and Drift Indicator | 3 |
| Weather Radar | 2 |
| Heading Hold Autopilot Mode | 2 |
| Hover Hold Autopilot Mode | 2 |
| Automatic Transition Autopilot Mode | 2 |

It should be noted that, whilst the proportion of the total number of cases where a Radio Altimeter would be of benefit was 23 out of 30, similar figures for Low Height Warning and Automatic Voice Alerting Device were 21 and 22 out of 30 respectively. This reflects the different ways in which the 3 items of equipment are used.

The Radio Altimeter is primarily employed for height keeping over the sea or flat terrain with the DH facility used to flag unintentional loss of height. However in several of the cases considered it was employed during landing, in poor visibility conditions, to gauge the distance to ground contact.

The Low Height Warning and Automatic Voice Alerting Device are designed to warn of unintentional descent through the decision height primarily over the sea in conjunction with a radio altimeter. As such they have no application when deliberate descents or low height manoeuvres are carried out.

### 4.5.1 *Radio Altimeter*

The correct and full use of a radio altimeter has been found or judged beneficial in 23 of the 30 cases analysed. This represents the highest ranked equipment of those considered in this study in that it had the potential to help prevent the highest number of accidents and incidents.

If the study had included the 'over water' cases only, this figure would have been proportionally higher.

In 4 of the 30 cases there was a known problem with the instruments, 3 of these being with the radio altimeter, the other with the barometric altimeter. Of the 3 radio altimeter problems, one was that the DH warning was obscured, the other 2 being malfunctions.

### 4.5.2 *Radio Altimeter Height Hold Autopilot Mode*

For 16 of the 30 cases, if a radio altimeter autopilot hold had been available and used the occurrence may have been prevented.

A radio altimeter height hold autopilot mode is a fundamental item of equipment which is necessary for maintaining surface separation for overwater flying. It is of note that some accidents of this study occurred in the early 1980's when the radio altimeter height hold was not a commonly available function and some public transport category oil support helicopters were operating without this autopilot facility.

### 4.5.3 *Heading Hold Autopilot Mode*

Use of the heading hold autopilot mode would only have been of minor benefit, and in only 2 of the cases analysed. Generally the heading hold is the most commonly occurring autopilot function, and easily engaged/disengaged.

For the 2 cases of benefit it is believed that the heading hold benefit was purely in reducing pilot workload in order that the pilot could have given greater attention to other piloting aspects.

### 4.5.4 *Airspeed Hold Autopilot Mode*

Use of an airspeed hold may have been of benefit in 8 of the cases. Apart from allowing the pilot more time for other duties there were 2 other occasions where the airspeed hold could have been of benefit, i.e.

(a) In maintaining a safe airspeed higher than the minimum airspeed in IMC ($V_{MIN\ IMC}$). In one case, during high turbulence the airspeed had inadvertently been allowed to fall to a speed where a handling problem occurred.

(b) On a number of occasions when inadvertent IMC had occurred, an automated 180° back track AFCS mode would have been of benefit which would have employed a combination of height hold, turn co-ordination and airspeed hold.

### 4.5.5 *Hover Hold Autopilot Mode*

Hover hold autopilot mode may have been of benefit in only 2 of the 30 cases analysed.

The study concentrated upon en-route cases rather than manoeuvring flight at the start/end of the sortie. One of the two applicable cases was a SAR mission where hover hold autopilot is a standard fit, however the system was not used, despite being available. The other was an attempt to land in blowing snow. This autopilot mode could have been used to stabilise the aircraft in the whiteout conditions, had it been available.

### 4.5.6 *Turn Co-ordination Autopilot Mode*

A turn co-ordination autopilot mode was judged to be of benefit in 7 of the 30 cases. Turn co-ordination by itself would not have prevented any of the cases but would have been of most use in automation of a 180° back track upon encountering inadvertent IMC.

### 4.5.7 *Auto Transition Autopilot Mode*

Use of automatic transition autopilot mode to (or from) the hover was judged beneficial in 2 of the 30 cases.

Each of these cases was judged beneficial due to the conditions of poor external cues due to low light and glassy water surface.

### 4.5.8 *Low Height Warning System*

Implementation of improved low height warning displays may have been of benefit in 21 of the 30 cases.

The 'Generic' improvement of low height warning over a standard radio altimeter could be anything from warning repeaters fed to the central warning panel to audio/visual cues provided by a head up display system.

### 4.5.9 *Automatic Voice Alerting Device*

AVAD was judged beneficial as possibly preventing 22 of the 30 cases.

AVAD was known to be fitted to the aircraft in only 4 of the cases, and in each case the equipment was judged to have been used in a sub-optimum manner. In 3 of these cases the audio warning was too late and the pilot was already attempting recovery, one of these being flight into rising ground, the others over the sea. In the fourth case the audio warning went unnoticed by both pilots.

The key issue with this, and the previous solution, is that a fully compelling warning of altitude transgression is made.

4.5.10 *Ground Proximity Warning System*

Thirteen of the cases may have been prevented by a suitable GPWS.

Of these 13 cases there are 2 types of occurrence, first, an unnoticed rate of closure with the surface, and second, flight into rising ground.

GPWS would have provided a warning early enough for the pilot to take avoiding action although careful consideration needs to be given to the manner of implementation for helicopters.

4.5.11 *Flight Path Warning System*

A flight path warning system was judged beneficial in 11 of the 30 cases.

Basically these cases, whether over land or water, are where handling difficulties have been experienced due to the aircraft entering a dangerous flight condition, for example high nose up attitude with low airspeed and a rate of descent.

Although no flight path warning system presently exists for helicopters, when available, it must be able to differentiate when these flight conditions are being deliberately flown and whether they are appropriate to the phase of flight.

4.5.12 *Ground Speed and Drift Indicator*

A ground speed and drift indicator system was judged beneficial in 3 of the 30 cases.

These 3 cases fell into 2 distinct categories; 2 involved low speed manoeuvring with poor external reference and one where the windspeed was very high causing a windspeed/ground speed correlation problem.

A ground speed and drift indicator would not in itself have prevented the accidents but would have aided the pilots in available knowledge to avoid the circumstances of the accident.

4.5.13 *Weather Radar*

Weather radar was judged beneficial in 2 of the 30 cases. Both of these cases were subject to the pilots pressing on into bad weather, having received poor forecasts. Use of a weather radar would have allowed them to make an earlier decision to alter course avoiding poor visibility which can lead to cases of disorientation.

4.5.14 *Obstacle Avoidance System*

An obstacle avoidance system would have been of benefit in 3 of the 30 cases.

Again due to the high number of over water cases in this study this is an appreciably low figure.

4.5.15 *ATC Facilities*

Improved, or improved use of, air traffic control facilities were judged to be beneficial in 5 of the 30 cases.

All 5 cases are over land. One case involved an ATC error resulting in failure to pick up the ILS. Two cases resulted from not electing to carry out an ILS despite being suitably equipped.

One case would have benefited by electing to transit at a higher altitude under ATC IFR procedures.

The fifth case was an inadvertent IMC case which would have benefited by better use of ATC and weather forecasts.

4.5.16 *Approach Aids*

Improved approach aids were judged to be beneficial in 11 of the 12 approach/landing cases.

Generally most of these 11 cases were operations into remote sites or offshore installations where no approach aid facilities existed.

The key function of the approach aid would be to compensate for the lack of, or misleading visual cues on approach. A further benefit may be to allow the aircraft to operate safely in lower weather minima than are presently applicable.

4.5.17 *Improved Displays*

Improved displays, of height or other flight parameters may have helped prevent 23 of the 30 cases investigated.

Generally a display of flight parameters allowing the pilot to maintain a view outside the cockpit would be beneficial to most cases considered, where poor external visual cues and too little monitoring of instruments are a factor.

# 5 FUTURE SYSTEM FUNCTIONAL REQUIREMENTS

## 5.1 Introduction

This section identifies the future system requirements for a system or systems that, when fitted to the helicopter or employed within the helicopter operating environment, could reduce and ideally avoid accidents/incidents involving surface collision.

To achieve this, the database information on the circumstances that existed just prior to the accident/incident was used to identify the problems that existed in each of the cases considered in this study. Having identified these problems, the actions to be undertaken to resolve them and so prevent similar accidents or incidents occurring in the future, could be determined. These actions lead directly to the identification of requirements for a future system.

The future system requirements identified define the ideal solution to the case. They identify a solution that will solve all problems associated with each case. In many, if not all cases, a single system combining all these requirements is not available now or in the foreseeable future. Therefore, it was decided to identify potential solutions that exist now or will exist in the future, and that address one or more of the problem aspects identified. These potential solutions were then evaluated against each case to give an indication of how effective each solution will be at avoiding the problems associated with each case.

This led to the identification of the most effective solution for each case. This solution is the recommended solution to be fitted to the helicopter or implemented in the helicopter operating environment, from a safety benefit point of view, as it has been determined to have the greatest effect at reducing or avoiding the problems identified.

The steps required to arrive at the identification of the most effective solution are:

- Identification of the Problems
- Identification of the System Requirements
- Identification of the Potential Solutions
- Methodology for Determining the Most Effective Solutions
- Identification of the Most Effective Solutions

These steps are described in greater detail below.

Throughout the following analysis of the data, it is important to be aware that only 30 cases have been considered. Therefore, when considering the following results and conclusions, it is important to appreciate that they have been derived from a statistically small sample of cases. Nevertheless, there are definite trends that can be identified from this data, and conclusions drawn from it. In the future, it is hoped that further cases could be added to the accident/incident database to improve confidence in the statistical analysis, therefore substantiating the results of this study.

## 5.2 Identification of the Problems

The problems for each case were determined by applying a set of rules to the information contained within the accident/incident database. The outcome of the rules determined whether there was a problem with this aspect for a particular case.

From the information within the accident/incident database, it was possible to identify 46 potential problem aspects and these are described briefly below. For a more detailed description of problem aspects, the rules and the resulting problem aspects table generated by application of the rules to each case, see Appendix E – Table of Problem Aspects.

| Problem Aspect | Description |
|---|---|
| Poor Procedures | Identifies whether there was a problem as to whether the procedures were being followed or were adequate for the task. |
| Poor Visibility | Identifies the level of visibility outside the aircraft just prior to the accident/incident and whether it was likely to have any influence on the accident/incident. |

| | |
|---|---|
| Poor Textural Cues | Identifies whether the crew experienced any problem with lack of surface textural cues just prior to the accident/incident. |
| Poor External Horizon Cues | Identifies whether the crew had problems with distinguishing a clear horizon just prior to the accident/incident. |
| Poor Transparencies | Identifies if the crew experienced any problem with the ability to see the outside world due to the size, location and quality of the cockpit transparencies just prior to the accident/incident. |
| Training/Experience Problem | Identifies whether the crew, if they had had more training or more experience, would have been more likely to have avoided the accident/incident. |
| Insufficient External Monitoring | Identifies whether the crew were monitoring the external cues insufficiently just prior to the accident/incident. |
| Excessive External Monitoring | Identifies whether the crew were monitoring the external cues excessively just prior to the accident/incident. |
| Insufficient Instrument Monitoring | Identifies whether the crew were monitoring the instruments insufficiently just prior to the accident/incident. |
| Excessive Instrument Monitoring | Identifies whether the crew were monitoring the instruments excessively just prior to the accident/incident. |
| High Workload | Identifies the level of workload experienced by the crew and whether it was high just prior to the accident/incident. |
| Crew Interaction Problem | Identifies if there is any problem associated with the crew communication. |
| Poor Cockpit Layout | Identifies whether the layout of the instruments, switches and flight controls was poor and therefore, could have contributed towards the accident/incident. |
| Poor Rad Alt Display Clarity | Identifies whether the clarity of the Radio Altimeter displays within the cockpit was a problem. |
| Poor Altimeter Display Clarity | Identifies whether the clarity of the Altimeter displays within the cockpit was a problem. |

| | |
|---|---|
| Poor Rad Alt Display Assimilation | Identifies whether the crew had a problem assimilating the information displayed to them on the Radio Altimeter displays just prior to the accident/incident. |
| Poor Altimeter Display Assimilation | Identifies whether the crew had a problem assimilating the information displayed to them on the Altimeter displays just prior to the accident/incident. |
| Audio Height Warning Not Compelling | Identifies whether the audio height warning given just prior to the accident/incident, was not suitably compelling to alert the crew to the problem, e.g. it was unnoticed by the crew. |
| Audio Height Warning Insufficient | Identifies whether the audio height warning given just prior to the accident/incident was insufficient to alert the crew to the situation, e.g. it was too late. |
| Audio Height Warning Not Understood | Identifies whether the audio height warning given just prior to the accident/incident was misunderstood by the crew. |
| Roll – Poor Instrumentation | Identifies whether improving the roll instrument fitted to the aircraft would have helped in avoiding the accident/incident by giving the crew the additional roll information. |
| Roll – Lack of Awareness | Identified whether lack of awareness of the roll of the aircraft was a factor in leading to the accident/incident. |
| Pitch – Poor Instrumentation | Identifies whether improving the pitch instrument fitted to the aircraft would have helped in avoiding the accident/incident by giving the crew the additional pitch information. |
| Pitch – Lack of Awareness | Identified whether lack of awareness of the pitch of the aircraft was a factor in leading to the accident/incident. |
| Yaw – Poor Instrumentation | Identifies whether improving the yaw instrument fitted to the aircraft would have helped in avoiding the accident/incident by giving the crew the additional yaw information. |
| Yaw – Lack of Awareness | Identified whether lack of awareness of the yaw of the aircraft was a factor in leading to the accident/incident. |

| | |
|---|---|
| Rate of Descent – Poor Instrumentation | Identifies whether improving the vertical speed indicator fitted to the aircraft would have helped in avoiding the accident/incident by giving the crew the additional rate of descent information. |
| Rate of Descent – Lack of Awareness | Identified whether lack of awareness of the rate of descent of the aircraft was a factor in leading to the accident/incident. |
| Air Speed – Poor Instrumentation | Identifies whether improving the air speed indicator fitted to the aircraft would have helped in avoiding the accident/incident by giving the crew the additional air speed information. |
| Air Speed – Lack of Awareness | Identified whether lack of awareness of the airspeed of the aircraft was a factor in leading to the accident/incident. |
| Ground Speed – Poor Instrumentation | Identifies whether improving the ground speed indicator fitted to the aircraft would have helped in avoiding the accident/incident by giving the crew the additional ground speed information. |
| Ground Speed – Lack of Awareness | Identified whether lack of awareness of the ground speed of the aircraft was a factor in leading to the accident/incident. |
| Wind Speed – Poor Instrumentation | Identifies whether improving the wind speed indicator fitted to the aircraft would have helped in avoiding the accident/incident by giving the crew the additional wind speed information. |
| Wind Speed – Lack of Awareness | Identified whether lack of awareness of the wind speed of the aircraft was a factor in leading to the accident/incident. |
| Wind Direction – Poor Instrumentation | Identifies whether improving the wind direction indicator fitted to the aircraft would have helped in avoiding the accident/incident by giving the crew the additional wind direction information. |
| Wind Direction – Lack of Awareness | Identified whether lack of awareness of the wind direction of the aircraft was a factor in leading to the accident/incident. |

| | |
|---|---|
| Translation – Poor Instrumentation | Identifies whether improving the translation instrument fitted to the aircraft would have helped in avoiding the accident/incident by giving the crew the additional translation information. |
| Translation – Lack of Awareness | Identified whether lack of awareness of the translation of the aircraft was a factor in leading to the accident/incident. |
| Altitude – Poor Instrumentation | Identifies whether improving the altitude instrument(s) fitted to the aircraft would have helped in avoiding the accident/incident by giving the crew the additional altitude information. |
| Altitude – Lack of Awareness | Identified whether lack of awareness of the altitude of the aircraft was a factor in leading to the accident/incident. |
| Heading – Poor Instrumentation | Identifies whether improving the direction indicator fitted to the aircraft would have helped in avoiding the accident/incident by giving the crew the additional heading information. |
| Heading – Lack of Awareness | Identified whether lack of awareness of the heading of the aircraft was a factor in leading to the accident/incident. |
| Track – Poor Instrumentation | Identifies whether improving the track indicator fitted to the aircraft would have helped in avoiding the accident/incident by giving the crew the additional track information. |
| Track – Lack of Awareness | Identified whether lack of awareness of the track of the aircraft was a factor in leading to the accident/incident. |
| Air/Ground Correlation Problem | Identifies whether the crew had a problem with correlating the ground and air speed just prior to the accident/incident, where the information could be available from either the instruments or using visual cues or a combination of both. |
| Vortex Ring Detection Problem | Identifies whether the crew where unaware of the fact that they were about to or had entered a vortex ring state just prior to the accident/incident. |

Using this classification of problem aspects, it is possible to analyse each accident/incident case in terms of which problem occurred in each case, and whether it occurred under certain conditions, such as at night or in fog.

The following sections firstly discuss the frequency of each of the problem aspects across the 30 cases considered, and identifies the most common problem area. Then, the cases are considered in terms of the circumstances of the accident/incident, i.e. whether the accident/incident occurred in fog, at night, during a particular phase of flight, and whether it resulted in the loss of control of the aircraft.

### 5.2.1 *Order of Problem Aspects*

For the accident/incident cases considered, it is possible to order the problem aspects based on the number of cases that definitely have a problem with this aspect or potentially have a problem with this aspect. (The determination of the problem aspects of the cases considered for this study are detailed in Appendix E of Volume 2 – Table of Problem Aspects). Table 5–1 gives the resulting order for the problem aspects.

From Table 5–1, it is possible to see that, from the cases analysed, the key problem aspects that contributed towards these type of accident/incidents are insufficient instrument monitoring, lack of awareness of rate of descent and lack of awareness of altitude. Therefore, improvement in these areas would have a significant effect on reducing the possibility of similar accidents/incidents occurring in the future.

It can also be seen that, out of the problem areas considered, there was no problem identified with yaw, the radio altimeter display clarity, the assimilation of the radio altimeter or barometric altitude information by the crew, awareness of translation or track information, or heading instrumentation. As a result, any solution that improves these areas would not reduce the possibility of any similar accidents/incidents to those considered in this study, occurring in the future.

Poor visual cues is an important area with all the problem aspects associated with external visibility being in the top 10 problem aspects. Out of all the cases with problems with excess external monitoring, all but 4 of these cases had some problem with the visual cues.

High workload was identified as a problem in 13 cases (i.e. over a third of the cases). Out of the 14 cases where there was more than one crew member present, 9 of them were judged to have a crew interaction problem (which is close to two thirds of these cases).

**Table 5–1 – Table of Ordered Problem Aspects**

| Problem Aspect | No. of Definite Problems from 30 Cases | No. of Potential Problems from 30 Cases |
|---|---|---|
| Insufficient Instrument Monitoring | 27 | 0 |
| Rate of Descent – Lack of Awareness | 21 | 2 |
| Altitude – Lack of Awareness | 17 | 8 |
| Poor External Horizon Cues | 16 | 8 |
| Excess External Monitoring | 16 | 0 |
| Poor Visibility | 14 | 9 |
| Poor Textural Cues | 14 | 1 |
| High Workload | 13 | 0 |
| Poor Procedures | 10 | 5 |
| Crew Interaction Problem | 9 | 4 |
| Pitch – Lack of Awareness | 7 | 1 |
| Insufficient External Monitoring | 7 | 0 |
| Training/Experience Problem | 4 | 0 |
| Air Speed – Lack of Awareness | 3 | 3 |
| Audio Height Warning Insufficient | 3 | 0 |
| Air/Ground Correlation Problem | 3 | 0 |
| Altitude – Poor Instrumentation | 2 | 8 |
| Air Speed – Poor Instrumentation | 2 | 3 |
| Ground Speed – Lack of Awareness | 2 | 1 |
| Rate of Descent – Poor Instrumentation | 1 | 2 |
| Roll – Lack of Awareness | 1 | 1 |
| Ground Speed – Poor Instrumentation | 1 | 1 |
| Wind Speed – Poor Instrumentation | 1 | 1 |
| Wind Direction – Lack of Awareness | 1 | 1 |
| Heading – Lack of Awareness | 1 | 0 |
| Excess Instrument Monitoring | 1 | 0 |
| Poor Cockpit Layout | 1 | 0 |
| Poor Altimeter Display Clarity | 1 | 0 |
| Audio Height Warning Not Compelling | 1 | 0 |
| Translation – Poor Instrumentation | 1 | 0 |
| Track – Poor Instrumentation | 1 | 0 |
| Vortex Ring Detection Problem | 1 | 0 |
| Poor Transparencies | 0 | 5 |
| Roll – Poor Instrumentation | 0 | 1 |
| Pitch – Poor Instrumentation | 0 | 1 |
| Wind Speed – Lack of Awareness | 0 | 1 |
| Wind Direction – Poor Instrumentation | 0 | 1 |
| Yaw – Poor Instrumentation | 0 | 0 |
| Yaw – Lack of Awareness | 0 | 0 |
| Poor Rad Alt Display Clarity | 0 | 0 |
| Poor Rad Alt Display Assimilation | 0 | 0 |
| Poor Altimeter Display Assimilation | 0 | 0 |
| Audio Height Warning Not Understood | 0 | 0 |
| Translation – Lack of Awareness | 0 | 0 |
| Track – Lack of Awareness | 0 | 0 |
| Heading – Poor Instrumentation | 0 | 0 |

### 5.2.2 *Controlled and Uncontrolled Flight*

This section compares the problem aspects that occur in the cases where the aircraft has collided with the surface whilst remaining in controlled flight against those where the aircraft has been out of control when it hit the surface. (Definitions of the terms controlled and uncontrolled flight are given in Appendix B).

Out of the 30 cases, 5 occurred when the aircraft was out of control, the rest in controlled flight. Figure 5–1 shows a graph of problem aspects for controlled, uncontrolled and all cases. The percentage value represents how many of the cases, within the specific category, include that particular problem aspect (i.e. if all the cases within the category have a problem with an aspect then the percentage value for that aspect will be 100%, as can be seen for Poor External Horizon Cues for Uncontrolled category of cases). The figure highlights the differences and similarities in terms of each problem aspect, for each category. The percentage value for each problem aspect obtained from averaging over all the cases has also been included as a reference, to allow comparison of categories of cases against the overall trend.

From Figure 5–1, it can be seen that the most common problem aspects for the cases involving uncontrolled flight are Poor Horizon Cues, Insufficient Instrument Monitoring, Poor Textural Cues and Excess External Monitoring. For the controlled flight cases, the top problem aspects are Insufficient Instrument Monitoring and Lack of Awareness of Rate of Descent and Altitude. Both categories have insufficient instrument monitoring as a key problem aspect. The emphasis in the uncontrolled cases is on the problem with visual cues, whereas the controlled flight cases are associated with a lack of awareness of the proximity of the aircraft to the surface.

When comparing the controlled and uncontrolled cases, it can be seen that the uncontrolled cases have a greater problem with awareness of pitch, air speed, wind speed and direction, but less of a problem with lack of awareness of rate of descent and altitude than the controlled cases. This suggests that the uncontrolled cases stem from a general lack of awareness of the helicopter situation within the environment whereas the controlled cases stem from unawareness of a slow descent towards the surface.

### 5.2.3 *Fog/Cloud*

This section compares the problem aspects that occur in the cases where the aircraft has collided with the surface whilst in fog or cloud with those where the aircraft was not in fog or cloud when it hit the surface.

Out of the 30 cases, 11 occurred when the aircraft was in fog/cloud. Figure 5–2 shows a graph of problem aspects for fog/cloud, no fog or cloud and all cases.

The most common problem aspects for the fog/cloud cases are Insufficient Instrument Monitoring and Lack of Awareness of Altitude. For the cases where there was no fog or cloud, the most common problem aspects are Insufficient Instrument Monitoring, Lack of Awareness of Rate of Descent and Excess External Monitoring. Hence, a common key problem aspect for both categories is the lack of sufficient instrument monitoring.

From Figure 5–2, it can be seen that for the no fog/cloud cases there were greater problems with the visual cues and the excess of external monitoring than with the fog cases. This would, perhaps, seem contrary to the results that might be expected. However, as some of the cases with fog/cloud occur whilst the aircraft is being flown under Instrument Meteorological Conditions (IMC), the problem with poor visual cues and excess external monitoring should be proportionally less than the cases of no fog/cloud, where all of these occur when the aircraft was being flown Visual Contact Flight (VCF). In the fog/cloud category, high workload and lack of awareness of the aircraft's altitude are more important problems than for the cases without fog/cloud.

Also, the comparison of the categories shows that lack of awareness of aircraft parameters is more of an issue in the no fog/cloud situation, with the exception of altitude and heading, than in the fog/cloud cases. This is possibly a result of the different level of instrument flying employed when the aircraft is in the fog/cloud than when it is not.

### 5.2.4 *Time of Day*

This section compares the problem aspects that occur in the cases where the aircraft has collided with the surface during the day against those where the aircraft was flying at night when it hit the surface.

Out of the 30 cases, 14 occurred during the day and 16 at night (of which 2 were at dawn). As a significantly smaller number of flights take place during the night than during the day, this suggests night flying is more of a problem than flying during the day (since the cases were not selected in favour of night flying accidents/incidents). Figure 5–3 shows a graph of problem aspects for day time flying, flying at night and all cases.

The most common problem aspects for both day and night time flying are Insufficient Instrument Monitoring, Lack of Awareness of Rate of Descent and Altitude. In addition, night flying has Excess External Monitoring and Poor External Horizon Cues as important problems.

Lack of awareness of aircraft parameters appears to be more of an issue for night time operations, in particular, the lack of awareness of pitch, air speed, ground speed and air speed/ground speed correlation.

### 5.2.5 *Phase of Flight*

This section compares the problem aspects that occur in the certain cases based on the phase of flight that the aircraft was judged to be in when the aircraft collided with the surface. The phases have been grouped into 2 figures only for reasons of clarity. The first group is of en-route phases of flight and the second group is of departure and arrival phases of flight.

Out of the 30 cases analysed, 3 occurred whilst the aircraft was flying high en-route, 12 when the aircraft was flying low en-route, 1 during an en-route hover, 2 occurred during take-off, 10 during approach and 2 during landing. (See Appendix E for a definition of the phases of flight.) With the exception of low en-route and approach, the sample of accidents/incidents in the particular phases of flight are very small, and so it is not possible to place much weight on any analysis carried out on them. Hence, the problem aspect trends shown by these phases of flight are only mentioned briefly in the following sections.

Out of the 30 cases considered, all of the 4 IMC cases occurred in fog, during the approach phase of flight, 5 cases occurred during controlled low en-route VCF night flight, 4 occurred during controlled VCF night flying whilst in fog on the approach phase and 3 occurred during controlled low en-route VCF flight during the day. Also, both landing phase cases occurred during controlled VCF night flight.

(a) *En-route Flight*

This section compares the problem aspects that occur in the cases where the aircraft has collided with the surface during low en-route flight, during en-route hover (e.g. Search and Rescue missions) and during high en-route flight.

Figure 5–4 shows a graph of the problem aspects for High En-route, Low En-route, En-route Hover and all cases.

From Figure 5–4, it can be seen that visual cues, instrument and external cue monitoring are problems, as well as poor crew interaction, lack of audio height warnings, lack of awareness of roll, pitch, rate of descent, air speed, ground speed, altitude, and air/ground speed correlation. There were no problems with the cockpit displays and their layout, or with the instrumentation, (excepting air speed and altitude instruments).

In the low en-route cases the most common problem aspect was poor instrument monitoring, with greater awareness required of the aircraft's rate of descent and altitude. In these cases, there was no problem identified with cockpit displays and crew awareness of wind, heading, track or yaw information.

(b) *Approach and Departure*

This section compares the problem aspects that occur in the cases where the aircraft has collided with the surface during take-off, approach or landing phases of flight.

Figure 5–5 shows a graph of the problem aspects for Take-Off, Approach, Landing phases of flight as well as all cases.

From Figure 5–5, it can be seen that the most common problem aspects are visual cues, excessive external cue monitoring, insufficient instrument monitoring, poor procedures and lack of awareness of the helicopter's altitude. The problems with cockpit displays and audio warnings are minimal during these phases of flight.

The approach phase cases have additional problems with air and ground speed and their correlation, but comparatively fewer problems with poor visual cues than the other phases of flight.

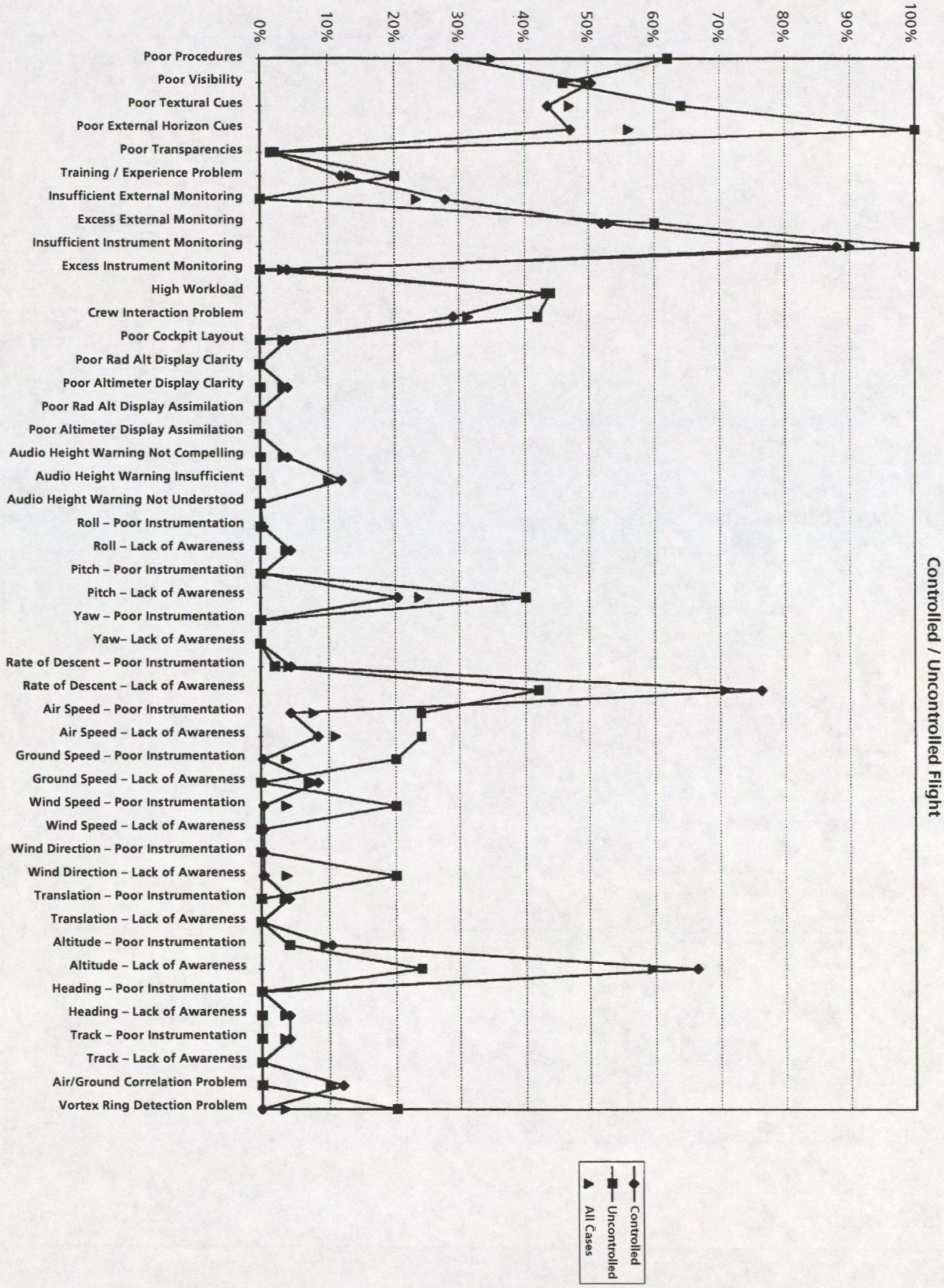


**Figure 5–1 – Controlled/Uncontrolled Flight**

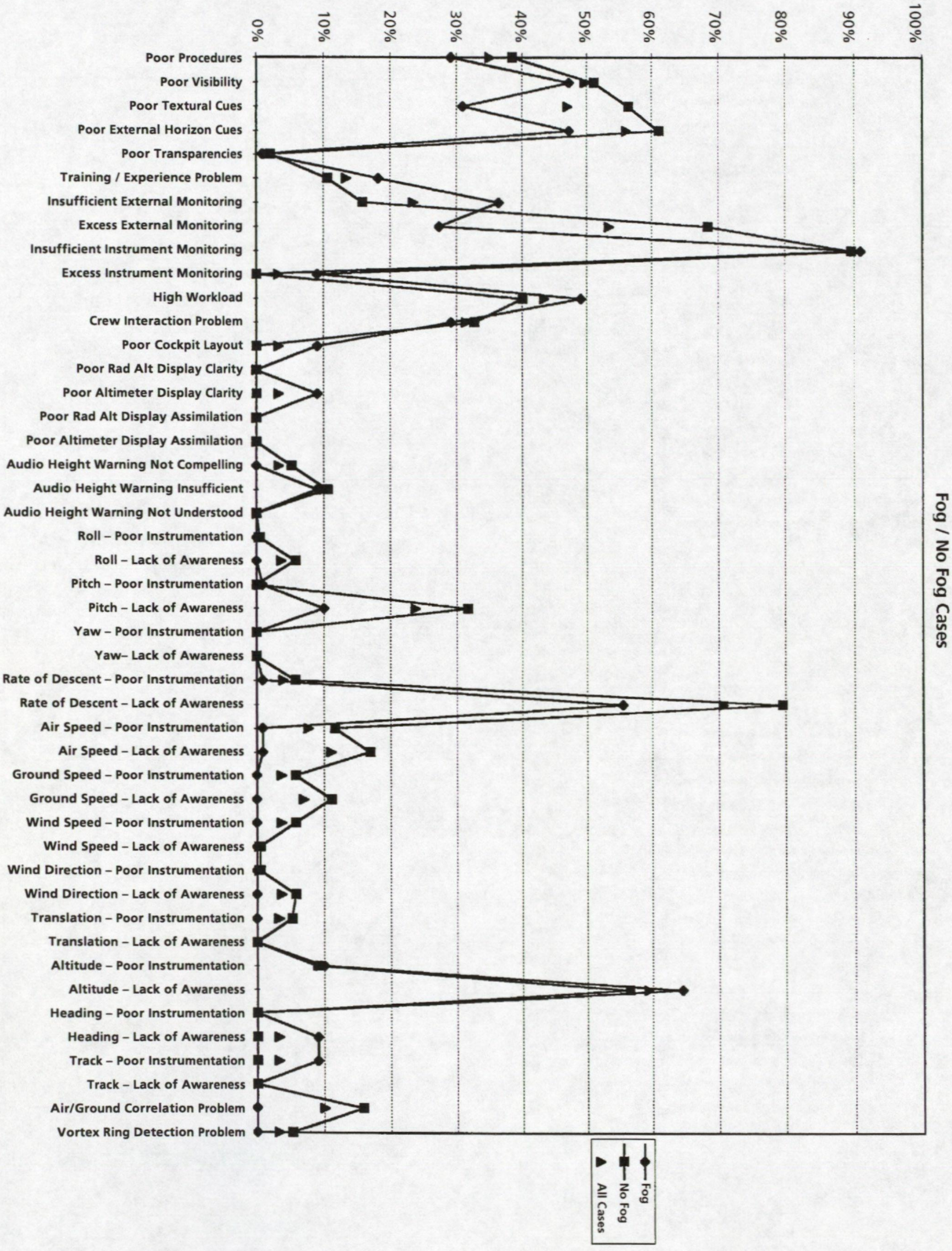


**Figure 5–2 – Fog/No Fog Cases**

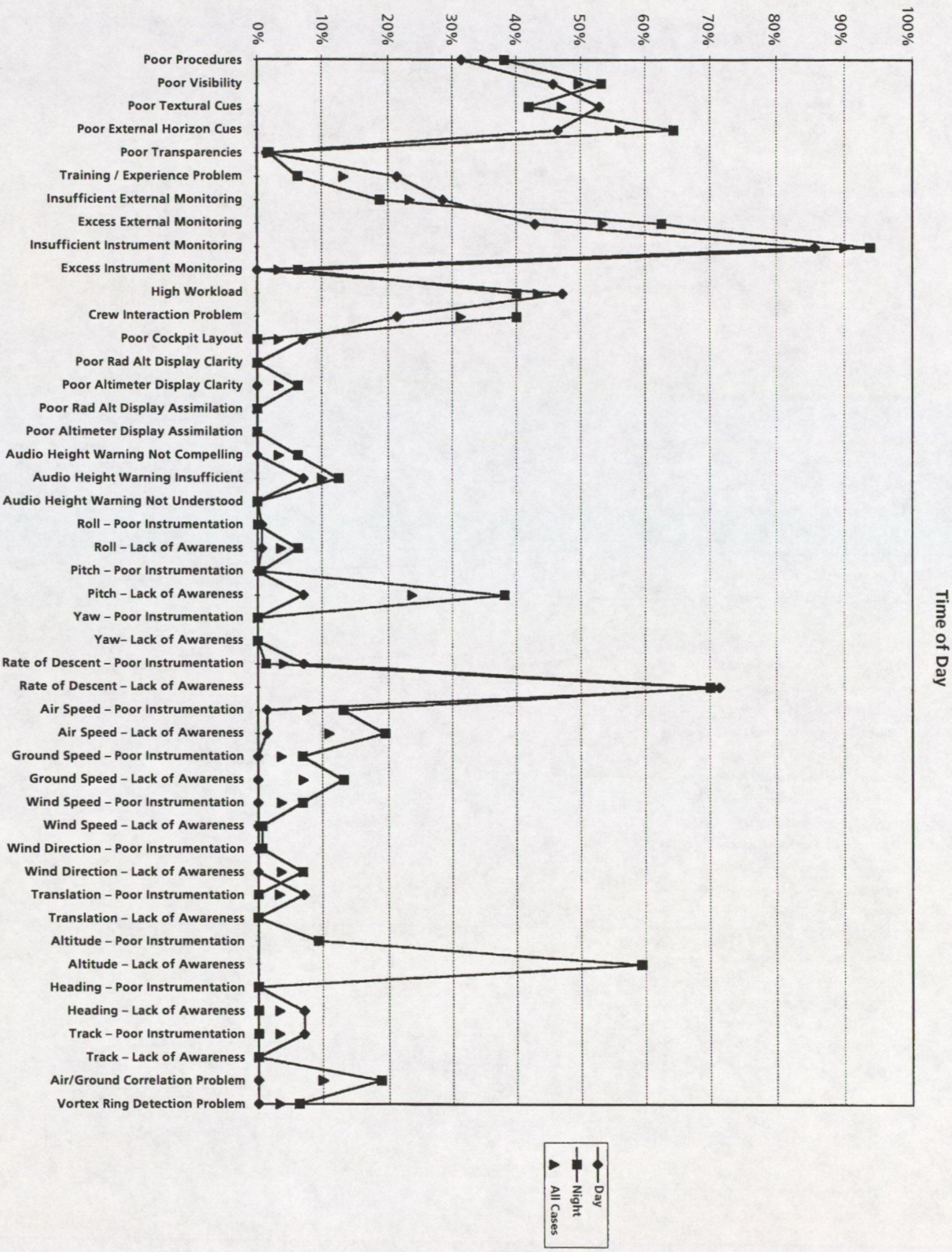


**Figure 5–3 – Time of Day**

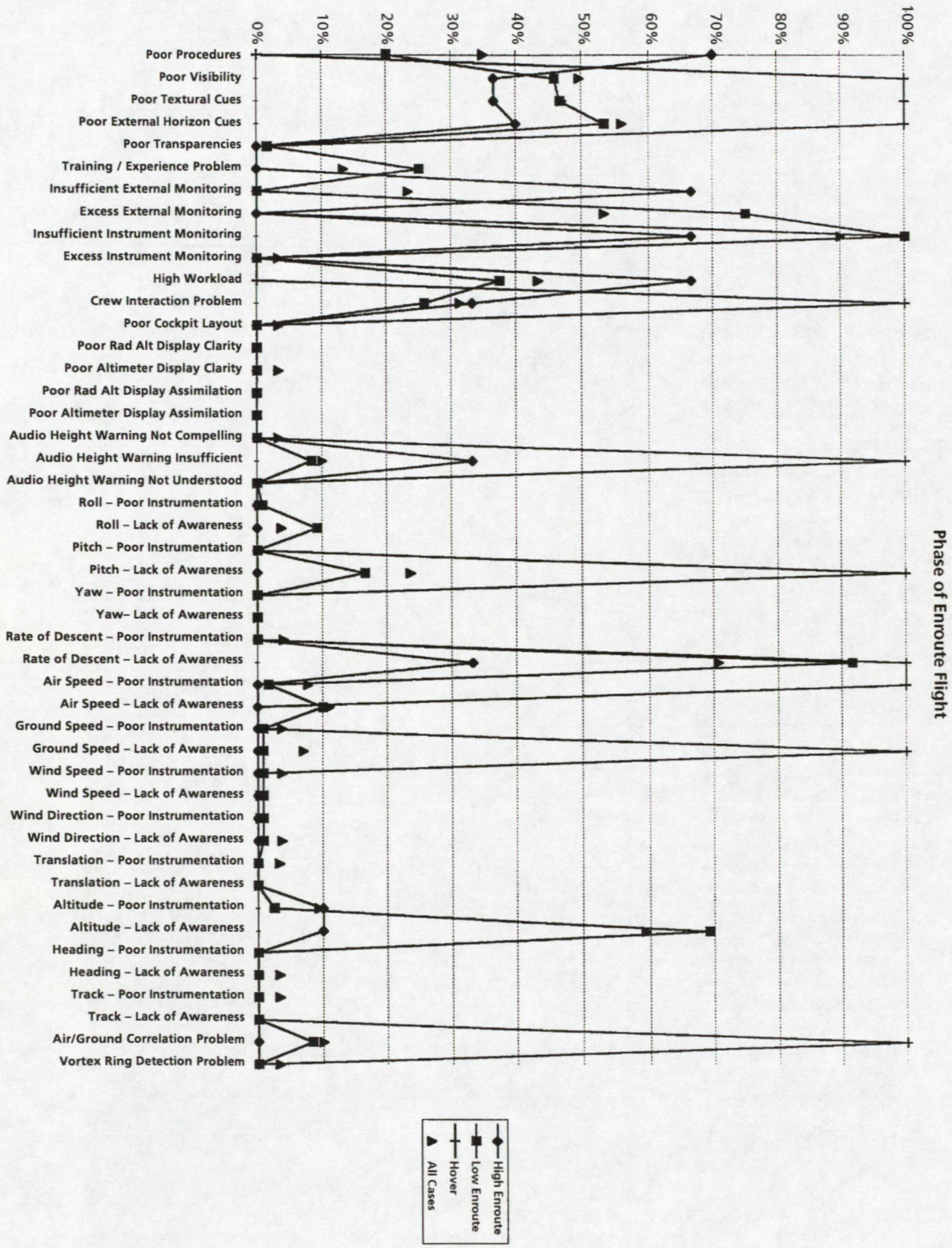


**Figure 5–4 – En-route Flight**

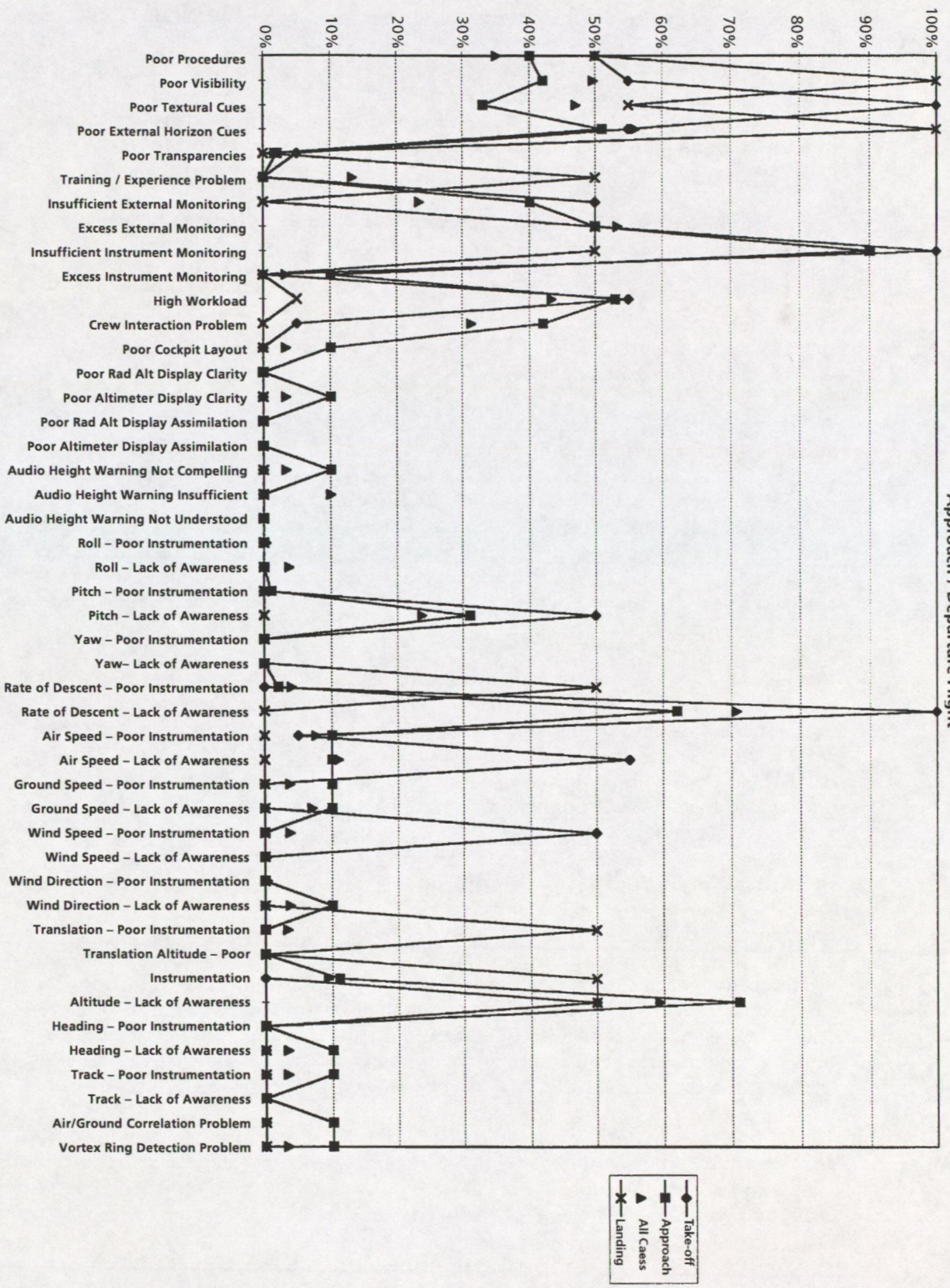


**Figure 5–5 – Approach and Departure Flight**

## 5.3 Identification of the System Requirements

From the Problem Aspects Table (Appendix E), it is possible to identify the areas which need to be addressed for each case, and for all the cases that have been analysed. This is achieved simply by looking at the problem areas identified for each case and determining from them the requirements to be satisfied to remove all of these problems areas for each case.

The requirements are briefly listed in Appendix F – Future System Requirements for each case, where the requirements are split into two categories:

- Essential Requirements – Requirements that would help avoid a similar case occurring in the future
- Desirable Requirements – Requirements that might help avoid a similar case occurring in the future

The determination of the requirements of a particular case is dependent on the data available within the accident/incident database for each case. If some information is unknown for a particular case then it has been assumed that this is not a factor that contributed to the accident/incident. For the purpose of this study it has been assumed that all contributory factors would have been noted in, or could be inferred from, the accident/incident investigation report. In the event that more information is added to the accident/incident database for each case, then the cases can be analysed further to identify new problem areas, which in turn would lead to more future system requirements.

Having identified the future system requirements for each case, it is possible to specify a system that, if implemented in the helicopter, or its environment, should avoid a similar case occurring in the future. However, in all instances a single system with all the requirements does not exist. Therefore, the options would be, depending upon the requirements, to integrate several existing systems or to develop a single system. Unfortunately, both options are likely to be complex and long term solutions.

## 5.4 Identification of the Potential Solutions

Identification of long term complex solutions to avoid the occurrence of similar cases in the future, although important in terms of identifying the fundamental requirements needed to be addressed for each case, does not lead to actions that can be taken in the short term to overcome the problem. Therefore, it was proposed that solutions that are available either now, in the short term or in the medium term future, should be identified and their ability to help to avoid accidents and incidents, similar to those covered in the database be assessed.

To achieve this, it was necessary to first identify the solutions that should be considered, and then to identify which problem aspects they address. This analysis would give some indication of how successful the solution would be at helping to avoid a similar accident/incident occurring in the future.

Appropriate solutions were identified by using the solutions generated as part of the Pilot Study for Advancing Technology for Future Helicopter Operations, funded by Shell Aircraft Limited, (Reference 4) as a basis. This study identified 189 solutions, but these covered all aspects of North Sea helicopter activity and thus many of them were not considered to be appropriate to the present study. The list of solutions was significantly reduced to centre on the areas that would help avoid surface collision accidents/incidents and this resulted in a list of 71 solutions (Table of Potential Solutions in Appendix G).

Each of the 71 solutions were then categorised in terms of which problem aspects they address and whether they could eradicate that problem or only partially address it. Using this information, in conjunction with the Table of Problem Aspects (Appendix E), it is then possible to make an assessment of how effective a given solution is expected to be at avoiding similar cases occurring in the future.

## 5.5 Methodology for Determining the Most Effective Solutions

Having determined the problems for the cases considered in the study and identified potential solutions and the problem areas that they address, some form of correlation is required to assess which solutions are best for each case and for all the cases considered. In order to do this, the following method, termed the Cost Value Method, has been developed. This method assesses each solution against every case, determining a value from this comparison, where the higher the value the better the solution addresses the problem areas of the case.

One of the main aims in the development of the method was to make it automated so that manual intervention will be minimal. Thus, the time to obtain the results should be significantly less than carrying out the comparison by hand. Having an automated method is essential when there are a significant number of solutions and cases to be compared. At present, with the limited number of cases considered in the accident/incident database, already 2130 comparisons are required (71 solutions to be compared against 30 cases). It is anticipated that the number of cases considered and the potential solutions available will increase. This will make the manual comparison task even more unrealistic and highlights the importance of making the method as automated as possible. Apart from the reduction in operator time required to run the method, automation leads to the identification of a systematic approach, the results of which will be unbiased, traceable and directly comparable.

Another aim was for the method to be as flexible as possible. This will then allow easy future expansion to incorporate more cases and problem aspects. This philosophy is also applied to areas of the method that have been based on judgement, such as the method rules, so that they can be easily modified to reflect any changes in judgement.

The Cost Value Method comprises the following steps:

1. Determine the method rules based on a classification of problem aspects in both the Problem Aspects Table and the Potential Solutions Table

2. Compare each solution against every case, using the rules to determine a Cost Value for each comparison

3. Determine the best solution for each case and all cases by ordering the solutions based on their Cost Value

The results from this method are described in Section 5.6, entitled Identification of the Most Effective Solutions.

### 5.5.1 *Determination of the Method Rules*

This section describes the development of the method rules and how this leads to obtaining a Cost Value for the comparison of a solution against a case.

The rules are a semi-formal way of detailing the assumptions that have been made when assessing a solution against a case. The rules set up in this method are:

1 The problem aspects assessment in the Table of Problem Aspects will only be considered in terms of True, Maybe and False

2 The assessment of the solutions against the problem aspects identified in the Potential Solutions Table will only be in terms of Yes, Partly and No

3 All problem aspects have equal weighting, i.e. no one aspect is more or less important than another problem aspect.

4 A solution can only address the problem aspects of a case if the solution operates under the conditions in which the case occurred (i.e. that phase of flight, in those fog conditions and at that time of day).

5 A problem aspect that might be a problem for a given case (i.e. a Maybe in a particular problem aspect column in the Problem Aspects Table) is a 10th as important as a definite problem for that case (i.e. a True in the same problem aspect column in the Problem Aspects Table), in terms of the influence it has on the accident/incident occurring.

6 A total solution (i.e. a Yes in the particular problem aspect column for the solution) to a definite problem area (i.e. a True in the associated problem aspect for the case) shall have a value, for that problem aspect, of 1000 (for scaling purposes only).

7 A partial solution (i.e. a Partly in a particular problem aspect column for the solution) will, on average, solve 25% of a definite problem aspect of a given case (i.e. a True in the corresponding problem aspect in the Problem Aspects Table).

8 If a solution does not solve any part of a problem aspect, then, for that problem aspect, it shall have a value of 0, as no avoidance of the problem aspect will occur and no influence on the accident/incident will be produced.

9 If the solution solves, partly or fully, any problem aspect that has not been identified as a potential or definite problem area, then no value shall be given, as this enhancement of an area that is not a problem will not avoid or reduce the possibility of the accident/incident occurring.

10 A problem aspect which is partly solved has more impact on avoiding the accident/incident, than a potential problem aspect which is fully solved (i.e. for a given problem aspect, Case having a True and Solution having a Partly should have greater value than Case having a Maybe and Solution having a Yes). The reason being that the first case is more important than the second. This is because the problem aspect in the first case is known to have a significant influence on the occurrence of the accident/incident whereas, in the second case it is not. Therefore, solving part of a problem aspect that is known to be a

significant factor in the accident/incident will have more chance of avoiding the occurrence than completely solving a problem aspect that might be a factor in the accident/incident.

From these rules it is then possible to assign values to the comparison of the solutions against the cases, where the values for comparison of solution against case for a particular problem aspect are:

**Table 5–2 – Determine Cost Values for Each Problem Aspect**

| *Case Problem Aspect* | *Solution* | *Value* |
|---|---|---|
| True | Yes | 1000 |
| True | Partly | 250 |
| True | No | 0 |
| Maybe | Yes | 100 |
| Maybe | Partly | 25 |
| Maybe | No | 0 |
| False | Yes | 0 |
| False | Partly | 0 |
| False | No | 0 |

These values are determined from the rules in the following manner:

For Case Problem Aspect = True and Solution = Yes, value = 1000 (from Rule 6)

For Case Problem Aspect = True and Solution = Partly, value = 1000 (from Rule 6)
* 25% (from Rule 7) = 250

For Case Problem Aspect = True and Solution = No, value = 0 (from Rule 8)

For Case Problem Aspect = Maybe and Solution = Yes, value = 1000 (from Rule 6)
* 1/10 (from Rule 5) = 100

For Case Problem Aspect = Maybe and Solution = Partly, value = 1000 (from Rule 6)
* 1/10 (from Rule 5)
* 25% (from Rule 7) = 25

For Case Problem Aspect = Maybe and Solution = No, value = 0 (from Rule 8)

For Case Problem Aspect = False and Solution = Yes, value = 0 (from Rule 9)

For Case Problem Aspect = False and Solution = Partly, value = 0 (from Rule 9)

For Case Problem Aspect = False and Solution = No, value = 0 (from Rule 9)

It should be noted that Rule 10 is upheld, as Case Problem Aspect = True and Solution = Partly (value = 250) is greater than Case Problem Aspect = Maybe and Solution = Yes (value = 100).

Having assigned the values to the comparison of a solution against a case for a particular problem aspect, it is then possible to determine the Solution Case Cost Value. This is done by first assessing the solution to be evaluated, to determine whether it can operate under the conditions under which the accident/incident occurred (from Rule 4). If it cannot, then the Solution Case Cost Value shall be set to 0 to indicate that the solution will be unable to help prevent a similar accident/incident occurring in the future. However, if it can operate under these conditions, then the Solution Case Cost Value is determined by the following equation:

$$\begin{aligned}\text{Solution Case Cost Value} = \; & K_1 * \text{Procedures Problem Aspect Value} \\ & + K_2 * \text{Visibility Problem Aspect Value} \\ & + K_3 * \text{Textural Cues Problem Aspect Value} \\ & \;. \\ & \;. \\ & \;. \\ & + K_{45} * \text{Air/Ground Correlation Problem Aspect Value} \\ & + K_{46} * \text{Vortex Ring Detection Problem Aspect Value}\end{aligned}$$

where $K_1$ to $K_{46}$ are weighting factors between the different problem aspects. In this study, the value of all these parameters is 1 as, from Rule 3, the problem aspects are assumed to have an equal effect on influencing the occurrence of the accident/incident.

By stating the rules in this manner and using them to determine the Problem Aspect Values and from that, the Solution Case Cost Values, it is possible to trace how the Cost Value has been determined. Also, if the rules need to be adapted, deleted or new rules need to be added, then it is relatively simple to redefine, delete or add the rules, and recalculate the Problem Aspect and Cost Values.

At this point, it should be noted that the absolute value of the Problem Aspect Value and of the Cost Values is not important. It is the relative value of the Cost Value against other Cost Values that is important, as these Cost Values allow one to determine whether the solution for a particular case is better or worse than the same solution on a different case, and whether it is better or worse than a different solution for the same case, by simply seeing which has the largest Cost Value.

### 5.5.2 *Comparison of Solutions Against Cases*

Having identified the rules and the means of determining a Cost Value that represents how effective a solution is at addressing the problem aspects for a given case, it is then possible to compare the effectiveness of one solution against another for a particular case and the effectiveness of a solution across all cases considered.

Using the Problem Aspects Values determined from the rules, the Solution Case Cost Value can then be automatically calculated for all solutions for every case. Having generated all these Cost Values, it is then possible to determine the most effective solution for each case, and by summing the Solution Case Cost Values for each solution, the most effective solution for all the cases contained within this study.

As mentioned above, the problem aspects within a given case are complex and unlikely to be solved by a single solution that is available either now, in the short term or the medium term future. To try to account for this problem, the method has been extended to evaluate the Cost Value for each case where the case is compared against a solution comprising of 2 of the solutions given in the Potential Solutions Table, combined together. This then allows the most effective combined solutions to be identified for each case and for all cases considered in this study.

It should be noted that no assessment has been made of how many problem aspects of a given case have to be addressed before it is reasonably certain that a case with the same circumstances will not occur in the future. If it was possible to determine the level at which an incident/accident would be avoided, based on the percentage of the problem aspects that were addressed by a solution, then it would be possible to use this method to determine which solution or combination of 2 solutions would avoid a similar case occurring in the future.

## 5.6 Identification of the Most Effective Solutions

Using the Cost Value Method described above, it is possible to order the solutions, given in the Potential Solutions Table, with the most beneficial solution first, through to the least beneficial solution, for each case and for all cases. This section discusses the results obtained from using this method to assess which solutions address most of the problem areas of each and all the accidents/incidents covered in this study.

### 5.6.1 *Most Effective Solutions for Each Case*

The following solutions have been determined to be the most effective for each case (where the selection of case numbers and their order are discussed in Section 2 entitled Identification of Cases to be Investigated).

**Table 5–3 – Most Effective Single Solution for Each Case**

| *Case No.* | *Solution No.* | *Percentage Problem Aspects Addressed* |
|---|---|---|
| 3 | 40 | 44% |
| 15 | 5 | 43% |
| 7 | 5 | 60% |
| 10 | 40 | 42% |
| 42 | 6 | 49% |
| 30 | 5 | 47% |
| 43 | 40 | 39% |
| 25 | 5 | 36% |
| 17 | 5 | 48% |
| 13 | 5 | 56% |
| 26 | 40 | 56% |
| 19 | 5 | 51% |
| 35 | 5 | 54% |
| 28 | 5 | 78% |
| 4 | 5 | 53% |
| 60 | 5 | 78% |
| 11 | 5 | 80% |
| 21 | 40 | 47% |
| 18 | 40 | 43% |
| 23 | 40 | 52% |
| 36 | 6 | 65% |
| 55 | 6 | 52% |
| 37 | 6 | 62% |
| 27 | 5 | 51% |
| 54 | 40 | 64% |
| 40 | 40 | 39% |
| 57 | 40 | 50% |
| 52 | 5 | 46% |
| 16 | 5 | 46% |
| 63 | 5 | 47% |

The case numbers relate to the numbers assigned to each case in the accident/incident database (remembering that the 30 cases were chosen from 65 applicable cases) and the solution numbers refer to the unique solution number assigned to each solution in the Potential Solutions Table. The percentage values column of the table represents the percentage of problem aspects that were addressed by the solution for that case from all the definite or potential problems exhibited by that case.

Out of the 30 cases considered in this study, Solution No. 5, the Intelligent Flight Path Monitor, is determined to be the most effective solution for 16 cases (which is over 50% of the cases considered). Solution No. 6, Automatic Flight Path Control, is deemed to be the most effective solution for 4 out of the 30 cases, which is less than a 6th of the cases. Solution No. 40, a Simple Helmet with Head Tracking to include a Horizon Line Display, is identified as the most effective solution for the remaining 10 cases (i.e. a third of the cases considered).

Hence, only 3 out of the 71 solutions considered were determined to be the most effective solution for any one of the cases. An overview of these 3 solutions is given in Section 5.7. However, Appendix H gives the top 30 solutions for each case. The top 3 solutions addressed, on average, 53% of the problem areas identified for each case.

The case with the lowest percentage problem areas addressed by the most effective single solution is case 25, at 36%. Case 25 was an uncontrolled flight into the sea whilst on approach under visual contact flight at night with degraded or misleading visual cues, poor crew communication and both pilots spending too much time monitoring the external cues and too little time monitoring the instruments. Neither pilots were adequately aware of the aircraft's pitch, wind direction, or had detected that they were about to enter a vortex ring state. In addition, they did not have sufficient knowledge of the aircraft's air speed or ground speed due to insufficient instrumentation in the aircraft's cockpit. The most effective solution for case 25 is Solution No. 5, an Intelligent Flight Path Monitor. This solution will address lack of awareness by the crew of the relevant instrument information, such as rate of descent, airspeed, and pitch, and warn the crew accordingly to avoid the aircraft entering a vortex ring state. However, Solution No. 5 will not be able to address the problem of the crew flying the aircraft under visual contact flight in a situation with poor and misleading visual cues, or give the crew ground speed or air speed data. As a result Solution No. 5 could only address 36% of the problem areas identified for case 25, although it was the most effective solution, out of the 71 considered, at addressing the majority of problem aspects in this case.

The case with the highest percentage of problem areas addressed is case 11, at 80%. This was a controlled IMC night flight into terrain in poor visibility whilst the aircraft was on approach. Both pilots were considered to be monitoring the external cues too much, the instruments too little and failing to follow the operating procedures. As the flight was in IMC, the fact that the visual cues were degraded should not have caused the accident as the crew should have been using their instruments to fly the aircraft. However, they were not monitoring the instruments adequately, as they were not sufficiently aware of their rate of descent and their altitude. The most effective solution for this case is an intelligent flight path monitor (Solution No. 5). Solution No. 5 will address the problems of inadequate awareness of rate of descent and altitude, and partly addresses the issue of procedures, since an intelligent flight path monitor would be capable of alerting the crew of a departure from the correct procedures. As a result, Solution No. 5 is able to address the majority of the problem areas of case no. 11.

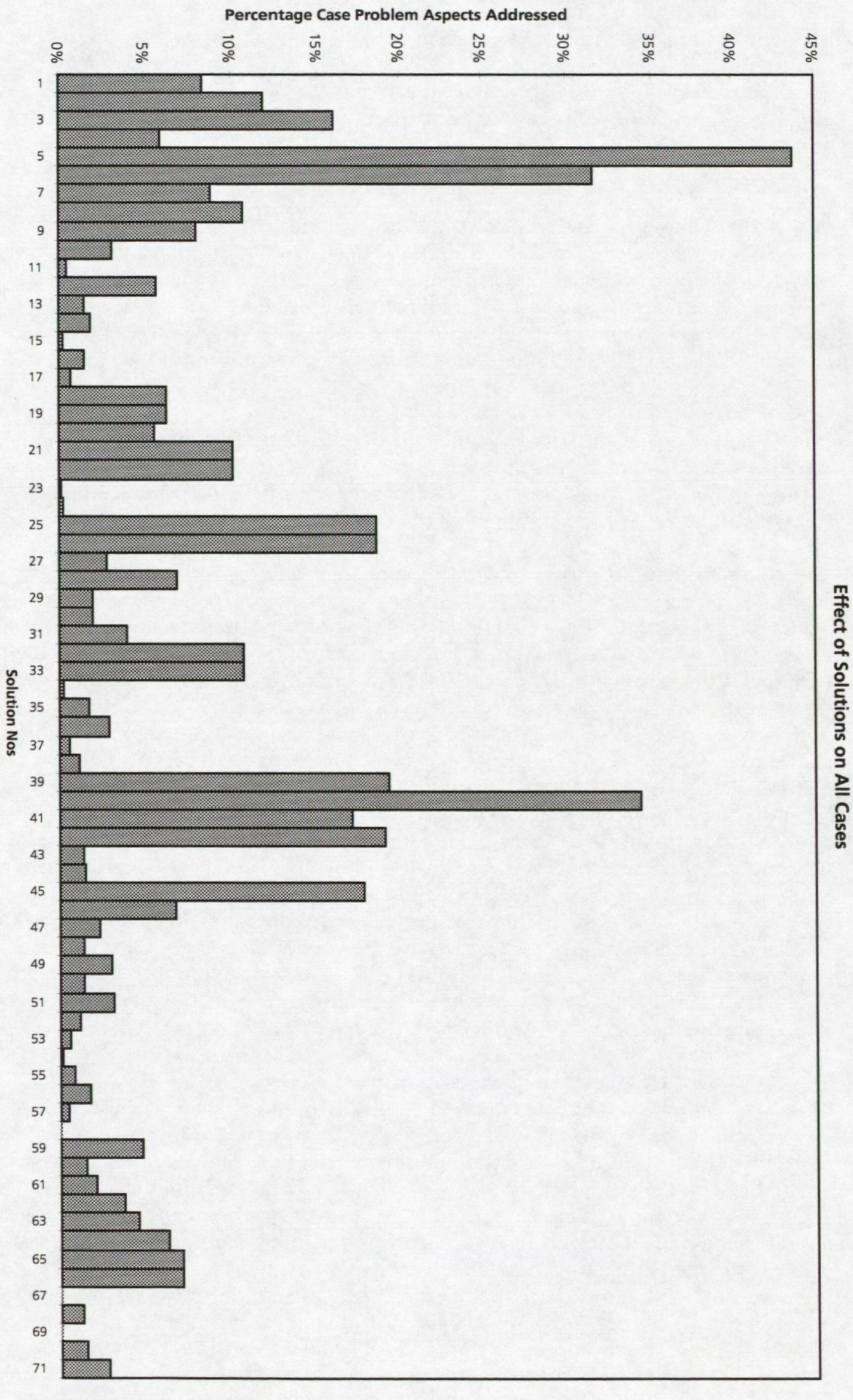


**Figure 5–6 – Effect of Each Solution on Addressing Problem Aspects for All Cases**

### 5.6.2 *Most Effective Solutions for All Cases*

This section considers each solution's ability to address all the problem areas identified from all of the cases considered in this study. The aim is to identify a single solution that addresses a high proportion of all the problem areas identified from all of the cases. If such a solution can be found this would mean that implementation of this solution would greatly reduce the possibility of all these types of accident/incidents occurring in the future, and therefore, would be an essential solution to be implemented into the current helicopter environment.

Figure 5–6 shows a bar chart of all 71 solutions, referenced by their solution number, against the percentage of the problem areas identified from all the cases considered. From the chart, it can be seen that solution numbers 58 (Improved Weather Radar Range Information Quality), 67 (Improved Aircraft Agility), and 69 (Audio or Voice Warning of Over Torque and Power Margin), do not address any of the problem areas identified within any of the cases considered. However, solution nos. 5 (Intelligent Flight Path Monitor), 40 (Helmet Mounted Display with Horizon Line Display), and 6 (Automatic Flight Path Control) address over a quarter of all the problem aspects identified by the cases. In particular, solution no. 5 addresses close to 45% of the problem aspects of all the cases.

No account has been taken of the cost, the ease of implementing the solution, and whether the solution is available as a product. An intelligent flight path monitor would be very complex and difficult to implement. It is not yet in production and therefore, not practical for the short term future and could only be implemented in the long term. For identification of a suitable solution for the short term future, the Cost Value method needs to be extended to take into account the practicality issues of implementing the solutions in the helicopter environment.

Some account of which equipment would have helped avoid the accident/incident has been covered in Section 4, Examination of Use of Available Equipment. In many cases there was insufficient information available from the accident/incident reports to determine the level of helicopter fit and, unlike the analysis carried out in this section (on Future System Functional Requirements), no assumptions were made about helicopter fit. Thus it was not possible within the work described in Section 4 to assess whether the benefit that would accrue from the equipment, would be in the addition of more information within the helicopter or, if the equipment was already fitted, the addition of warning devices to improve crew awareness of the information already provided. However, the section does identify the type of information that can be relatively easily added to the helicopter environment in the short term.

### 5.6.3 *Most Effective Combined Solutions for Each Case*

Having assessed how effective the potential solutions were at addressing the problem aspects of each individual case and of all cases combined, the effectiveness of any two of these solutions combined together was considered. To do this, each potential solution was functionally combined with every other potential solution, in turn, and these combined solutions compared against the case problem aspects. Table 5–4 below lists the most effective combined solutions for each case considered in this study:

**Table 5–4 – Most Effective Combined Solutions for Each Case**

| Case No. | Solution Nos. | Percentage Problem Aspect Addressed |
|---|---|---|
| 3 | 40 + 65, 40 + 66 | 67% |
| 15 | 5 + 32, 5 + 33, 5 + 40 | 70% |
| 7 | 5 + 40 | 92% |
| 10 | 5 + 40 | 79% |
| 42 | 5 + 6 | 66% |
| 30 | 5 + 40, 6 + 40 | 68% |
| 43 | 5 + 40 | 72% |
| 25 | 5 + 40 | 61% |
| 17 | 5 + 40 | 82% |
| 13 | 5 + 40 | 88% |
| 26 | 5 + 40 | 99% |
| 19 | 5 + 40 | 78% |
| 35 | 5 + 40 | 94% |
| 28 | 5 + 40 | 97% |
| 4 | 5 + 39, 5 + 41 | 70% |
| 60 | 5 + 40, 5 + 42 | 98% |
| 11 | 5 + 40, 5 + 42 | 98% |
| 21 | 5 + 40, 6 + 40 | 89% |
| 18 | 10 + 40, 20 + 40, 40 + 46, 40 + 49 | 71% |
| 23 | 5 + 40 | 74% |
| 36 | 5 + 7, 5 + 8 | 100% |
| 55 | 5 + 40, 6 + 40 | 86% |
| 37 | 6 + 40, 6 + 42 | 94% |
| 27 | 5 + 40, 6 + 40, 5 + 59 | 71% |
| 54 | 4 + 40, 7 + 40, 8 + 40, 10 + 40, 20 + 40, 40 + 46, 40 + 47, 40 + 48, 40 + 49 | 84% |
| 40 | 5 + 40 | 75% |
| 57 | 20 + 40 | 83% |
| 52 | 5 + 40 | 84% |
| 16 | 5 + 40 | 80% |
| 63 | 5 + 40 | 81% |

Where more than one combined solution is listed, it is because there is more than one most effective solution for that case, e.g. combined solutions 5 + 40 and 6 + 40 are equally as effective at addressing the problem aspects of case number 30.

There are 25 combined solutions that are most effective for one or more of the cases considered in this study, comprising of 20 single solutions. Out of these 25 combined solutions, solution numbers 5, the Intelligent Flight Path Monitor, combined with solution 40, the Helmet Mounted Display with Head Tracking for Horizon Line Display, is one of the most effective solutions for 22 of the 30 cases considered in this study (i.e. over two thirds of the cases). Solution number 6, Automatic Flight Path Control with solution number 40 is one of the most effective combined solutions for 5 out of the 30 cases (i.e. a sixth). Solution number 20, Precision Approach System (Coupled), with solution number 40 is one of the most effective combined solutions for 3 out of the 30 cases (i.e. 10% of the cases considered).

All cases, apart from case 36, include the most effective single solution as part of a most effective combined solution for that case. In case number 36, the single most effective solution was solution number 6, the Automatic Flight Path Control. However, in the combined solution, solution number 5, the Intelligent Flight Path Monitor, in conjunction with a Flight Management System (solution number 7 or 8) is the most effective solution (at 100%).

Only 25 out of the 2485 possible combined solutions considered were determined to be the most effective solution for one or more of the cases. Appendix I gives the top 30 combined solutions for each case.

The most effective combined solutions, on average, addressed 81% of the problem areas identified for each case. This is an increase of 28% overall from the percentage of problem areas addressed by the most effective single solutions. This increase is significant, as it means that overall, over 80% of the problem areas of every case are addressed, therefore, if one of the most effective combined solutions were implemented for each case, the probability of similar types of accidents/incidents occurring in the future should be small.

The case with the lowest percentage problem areas addressed is case 25, at 61%, which is an increase of 25% from the problem areas addressed by a single solution. The most effective combined solution for this case is composed of solution numbers 5 and 40. The benefits of solution no. 5 to this case are discussed above in the Most Effective Single Solutions section. The addition of a helmet mounted display that will display a horizon line when the pilot is looking head up (solution no. 40) will address some of the problems that the crew experienced with the visual cues. However, it will not address the problem with lack of information on air speed, ground speed or lack of awareness of wind direction. This is the reason that only 61% of the problem aspects of case 25 are addressed.

The case with the highest percentage problem areas addressed is case 36, at 100%. Case 36 was a controlled IMC flight into terrain, during the day whilst the aircraft was on approach, where the visual cues were poor or non existent, and both pilots where spending too little time effectively monitoring the instruments. As a result they had insufficient awareness of their rate of descent, their heading and their track. The most effective combined solutions are solution numbers 5 and 7 or 5 and 8, where solution no. 7 and solution no. 8 are both flight management systems. Solution number 5 will address the lack of awareness of the rate of descent, and the flight management systems will monitor whether the aircraft is on track and has the correct heading for this track, as it will have information on the current wind velocity. The lack of visual cues are not taken to be problem areas for this case, as the flight was carried out under IMC. Thus the crew should not be relying on any visual cues, and therefore, their quality is not important to the safety of the aircraft. As a result, these two combined solutions addressed all the problem aspects for this case, i.e. 100%, and therefore, if implemented, should avoid a similar case occurring in the future.

### 5.6.4 *Most Effective Combined Solutions for All Cases*

This section considers each combined solution's ability to address all the problem areas identified in all the cases considered in this study. The aim is to identify a combined solution that addresses a high proportion of all the problem areas identified. If such a combined solution can be found this would mean that its implementation would greatly reduce the chances of all these types of accident/incidents occurring in the future, and therefore, would be an essential solution to be implemented into the current helicopter environment.

Figure 5–7 shows a bar chart of the top 50 combined solutions which address the highest percentage of problem aspects identified from all the accidents/incidents considered in this study. From this chart it can be seen that all of these top 50 combined solutions solve more than 40% of all the problem aspects identified by the cases, with the top 25 solutions solving over half of the case problem areas identified. Also, all of these solutions include either solution no. 5 (Intelligent Flight Path Monitor), 6 (Automatic Flight Path Control) or 40 (Simple Helmet Mounted Display with Horizon Line Display) where these solutions were identified as the most effective single solutions for one or more of the accidents/incidents analysed.

The most effective combined solution for all the cases considered is the solution combining the Intelligent Flight Path Monitor (solution no. 5) and the Simple Helmet Mounted Display with Horizon Line Display (solution no. 40), with a percentage of case problem aspects addressed of over 75%. This combined solution is therefore effective at addressing the types of accidents/incidents considered and would significantly reduce their probability of occurring in the future if implemented in the helicopter environment. This is to be expected as the combined solution addresses the problems of lack of awareness of critical parameters such as rate of descent and altitude, alerting the pilot to any flight parameter that is outside or approaching the operating limits of the helicopter, for its environment, and improving the visual cues by generating an artificial horizon line in the pilot's field of view. These are all problem areas that featured as very significant in the assessment of problem aspects and are common problems for most, if not all, of the types of cases considered within this study.

The Cost Value method does not yet take into account the practicality of implementing the solution and therefore, recommendation of this solution is based purely on safety. As a result, the practicality, complexity and cost of implementing this combined solution in the helicopter has not been considered. It is anticipated that the method will be extended, in the future, to take this into consideration.

The combined solution composed of solution nos. 5 and 40 is particularly effective as it consists of the top 2 single most effective solutions, where these solutions happen to address almost totally different problem areas, and therefore, can be effectively combined. This is not the case when combining the 1st (solution no. 5) and 3rd (solution no. 6) single most effective solutions, where the problem areas addressed by both solutions are similar. Therefore, this combined solution does not improve as dramatically on the percentage of areas addressed by solution no. 5 on its own, 44%, to a combined percentage of 51%.

The other solutions that make up part of the top 10 combined solutions are external cue enhancement systems, such as Night Vision Goggles and Low Light TV Camera, proximity to surface warning systems, such as GPWS and GCAS, and flight management systems. The vision enhancement systems and flight management systems compliment the intelligent flight path monitor, as these are not areas addressed by the flight path monitor. The surface proximity warning systems compliment the Helmet Mounted Display with the Horizon Line.

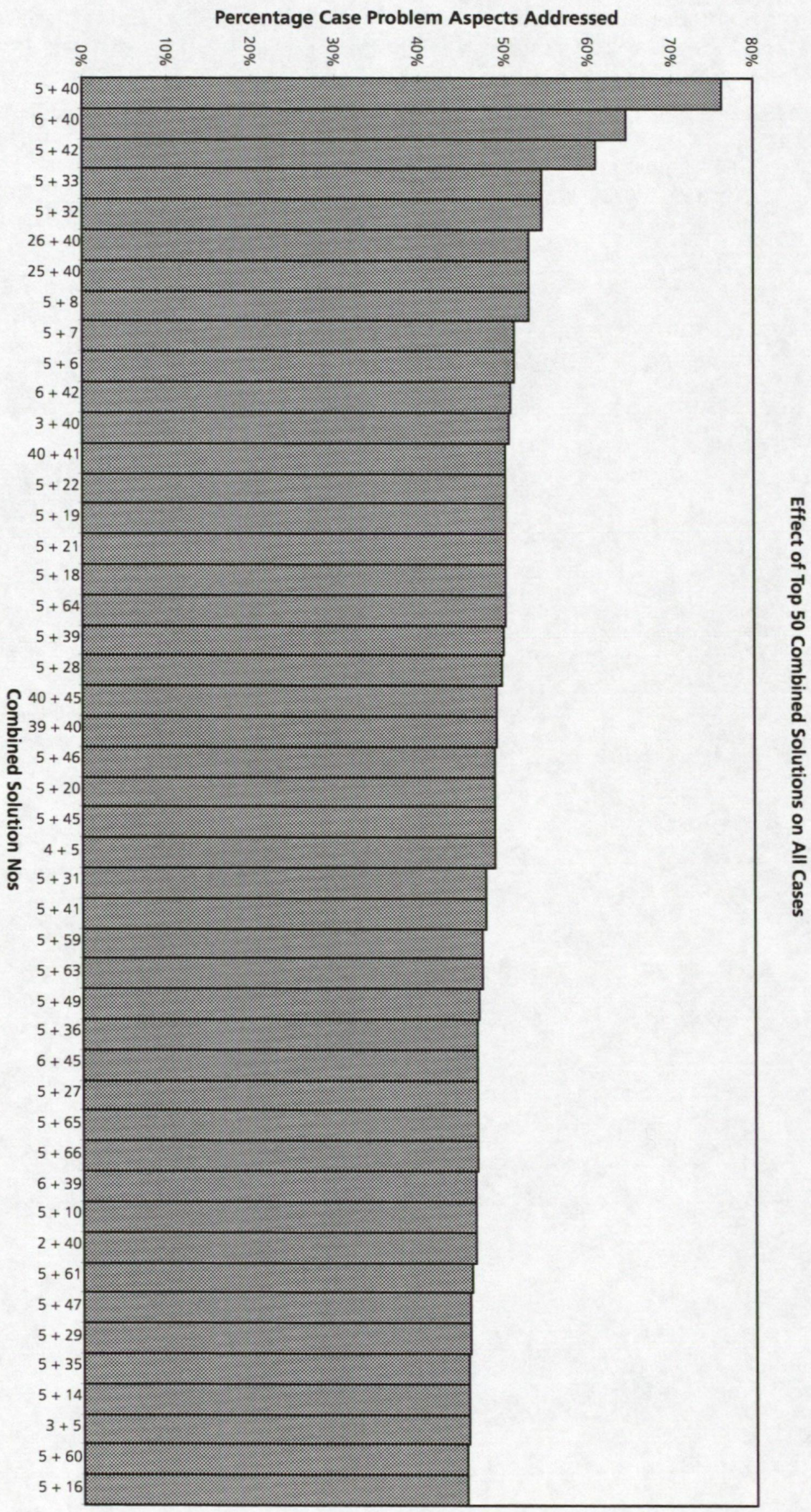


**Figure 5–7 – Most Effective Top 50 Combined Solutions for All Cases**

## 5.7 Overview of the Most Effective Solutions

This section gives an overview of the most effective solutions identified from the above analysis of the cases within the Accident/Incident Database (Appendix A).

### 5.7.1 *Intelligent Flight Path Monitor*

The monitoring system within the helicopter is currently basic and applies no intelligence when signalling to the pilot that some parameters are not within the expected tolerance. An Intelligent Flight Path Monitoring system would:

- Deduce from certain combinations of factors that there is a flight path deviation. This information could then be displayed to the pilot, allowing him to readily assimilate the problem without having to diagnose it himself. Thus, this could avoid pilot distraction in problem diagnosis and reduce pilot reaction time to the situation caused by the deviation.
- Monitor the pilot's actions. This could be achieved by an intelligent system such as ARCHIE ('A Reliable Computer-Human Interaction Environment'), where the monitor would have knowledge of the allowable flight envelope, procedural requirements and all the aircraft systems. The monitoring system could then be in a position to assess the pilot's actions, and give him timely and clear warnings when he is doing anything that does not conform with the known procedures or helicopter capabilities.

The ARCHIE system uses operator and environment information, together with pre-programmed knowledge about the application, to provide the level of support the human needs. Depending on the requirements of the application, ARCHIE support can range from the removal of unwanted information from a cluttered display, to generating specific advice on the best way of recovering from an operator error. The cost of implementation and complexity of the system will depend on the level of support provided. Several research projects are currently under way to develop the kernel for such an intelligent system.

### 5.7.2 *Automatic Flight Path Control*

Automatic flight path control would relieve the crew from flying the aircraft, automatically maintaining the attitude, altitude, speed and track of the helicopter. In conjunction with a Flight Management System (FMS), the helicopter can be automatically guided along the route, allowing the crew more time to devote to monitoring, communications and improving their situational awareness.

Implementation of automatic flight path control is expensive and complex. It requires the aircraft to have a sophisticated autopilot and the control algorithms require a suite of flight control systems including engine control and environmental monitors. This solution is currently being researched and several versions are already available.

### 5.7.3 *Simple Helmet with Head Tracking to include a Horizon Line Display*

A simple Helmet Mounted Display would allow the crew to monitor aircraft instruments together with external visual cues. They would be able to spend more time with eyes out of the cockpit and as a result, the crew will have better situational awareness, especially at night or in conditions of poor visibility.

If a head tracking system were attached to the helmet, world stabilised imagery could be overlaid, such as an artificial horizon, and a velocity vector. These would be similar to symbology already displayed on Head Up Displays (HUDs). The display could also be used to gather together essential data such as height, main rotor torque and speed. If a differential GPS system were available, a Helideck locator symbol could be generated, similar to the recovery base symbol used on military HUDs.

The technology to build HMDs exists, although the full systems are complex and expensive.

An inexpensive solution could be created by mounting a single 1 inch monochrome Cathode Ray Tube (CRT) on a lightweight plastic head cap. The CRT image would then be folded into the pilots eye using a simple optical system, so that the symbology would be overlain on a transparent eyepiece. The optics and CRT would be contained in a protective plastic housing, which would in turn be attached to a metal torus. All of the wiring and electronics would be contained in this torus.

The helmet would be connected to a separate electronics unit via an umbilical cable from the back of the helmet. The adjustable head cap and chin strap would secure it to the head. Rear weights would ensure that the Centre Of Gravity was maintained for maximum comfort.

*Future Possibilities*

(a) *LCD Displays*

The Monochrome CRT solution and all military helmet mounted displays to date, use CRTs as the image source. This is simply because they are the only possible image source small enough to be mounted on the head, and bright enough for the image to still be clearly discernible when using a transparent eyepiece.

In recent years there have been dramatic improvements in Liquid Crystal Displays (LCD). Miniature LCDs for helmet displays have been developed and can now produce 512x512 arrays which only measure 20x18mm. The only obstacle that remains is to increase the brightness.

(b) *Visor Projection*

The CRT solution discussed above uses a simple optical arrangement to carry the image from the CRT to the eyepiece. This results in image attenuation, and the mounting bracket and eyepiece housing partially obscure the pilot's view.

Research is currently being undertaken to develop the next generation of helmet where the optics and eyepiece will be dispensed with, and the image will instead be projected onto a specially treated patch on the pilot's visor.

## 5.8 Summary

This section has shown how problem aspects from each case can be identified, how this can lead to future system requirements and then to the identification of solutions that could prevent a recurrence of the circumstances of these cases. It has introduced an approach, termed the Cost Value method, which allows the identification of suitable solutions for each accident/incident in a methodical and therefore, unbiased and traceable manner.

This Cost Value method allows a formalised approach to identifying the judgements that need to be made to determine whether a solution is suitable for a particular case. It has been arranged to allow easy modification of these judgements, which make up the method rules, and will readily allow addition of new solutions, more cases and more problem areas, when, in the future, the accident/incident database is extended. The method is automated, and requires little user intervention, which is essential for a system with the potential to handle a large amount of data. The Cost Value method can be rapidly extended to take into account such factors as the practicality aspects of each solution, and so determine which solution has the greatest safety benefit, balanced against the practicality of implementing it into the helicopter environment.

The solutions determined from the above analysis are different from the solutions recommended from the Examination of Use of Available Equipment (Section 4). The reason for these differences being that consideration of solutions in this section was based on the increased functionality that they would bring to the helicopter environment. In Section 4 the value of the solution was determined irrespective of what other equipment was expected to be onboard the helicopter. As a result, no direct comparison can be made between the results of the two sections.

The analysis carried out in this section has identified insufficient instrument monitoring, and lack of awareness of the helicopter's rate of descent and altitude as the key problem areas for the cases considered in this study. High crew workload, poor crew interaction and poor visual cues are also aspects that have been highlighted as being common problem areas across many of the 30 cases.

It has been found that a few key solutions stand out as addressing the majority of the problem areas identified for the cases considered within this study. In particular, solution no. 5, the Intelligent Flight Path Monitor and solution no. 40, the Simple Helmet Mounted Display with Horizon Line Display, together address 76% of the case problems, and are one of the most effective combined solutions for 22 out of the 30 cases. Solution no. 5 is determined to be the best single solution, solving 44% of all the case problem aspects and being the most effective single solution for 16 out of the 30 cases.

# 6 CONCLUSIONS

A database analysis of 30 accidents or incidents in which serviceable helicopters either flew into the sea or ground, or came close to doing so, has allowed common circumstances relating to these occurrences to be identified. Additionally, the effectiveness of equipment that is currently available, or could soon be made available, in helping to prevent such accidents has been assessed. Finally, by identifying the problems that led to each incident, the functional requirements of a future system, or combination of systems, that aim to obviate such problems have been generated.

Twenty six of the 30 accidents/incidents analysed occurred during visual contact flight, the rest being carried out under instrument meteorological conditions. In all but one of the visual contact flight cases, visual cues from one or more aspects of the external environment were either degraded in some way or were non-existent. Of particular significance is that, in 19 cases, there were no external horizon cues and these were degraded in a further 7 cases. Other aspects that engendered particular difficulty in maintaining spatial awareness and orientation are flight over surfaces with no cues (such as glassy water or ice), and misleading feature cues, principally single light sources such as offshore platforms at night.

In 13 cases, high crew workload was a factor with poor or incorrect following of procedures also contributing to, or causing a problem in 15 cases. Of the 15 cases analysed with 2 crew, poor crew interaction was definitely a factor in 9 cases and possibly a factor in a further 4. Thus issues relating to workload, procedures and the division of tasks amongst the crew were a significant element in this analysis of surface collisions involving helicopters.

### 6.1 Currently Available Equipment

Consideration was given to equipment that is either currently available, or could soon be made available, in helping to prevent each case, if fitted and operated correctly. This showed that in 23 of the cases considered, a radio altimeter would have been of benefit. However, since these were fitted to the majority of helicopters considered, yet the accidents/incidents still occurred, there would seem to be a problem with assimilation of the altitude information being displayed. Thus a compelling height warning was deemed of benefit in 21 cases with AVAD being of slightly more use as it would have helped to prevent 22 cases. It is of note that only 4 of the 30 cases considered involved helicopters with AVAD fitted. This would suggest that AVAD, as currently configured, is mostly effective in preventing accidents involving surface collision, although without considering all helicopter accidents/incidents, this is difficult to ascertain for certain.

It is concluded that improved displays would have been of benefit in 23 cases where critical information was available but either not accessed by the crew or it was not presented in a format that was easily and correctly assimilated. A radio altimeter height hold autopilot mode would have helped prevent 16 cases. Thirteen cases with an unnoticed rate of closure with the surface or flight into rising ground would have been prevented by a ground proximity warning system.

A flight path warning system which warns the pilot that the aircraft has, or is approaching an unreasonable combination of flight parameters would have been of benefit in 11 cases. An equal number of cases would benefit from an approach aid. However, 12 of the cases analysed were in the approach/landing phase making the potential benefit of approach aids relatively more important.

Other systems considered would have helped in less than a third of the cases analysed but could be of merit in certain types of operation e.g. ground speed and drift indicator when hovering over snow.

## 6.2 Future Equipment

Looking beyond currently available equipment, the task to formulate functional requirements for a system, or combination of systems, to prevent helicopter surface collision incidents in the future involved carefully examining the accident/incident database via a series of formal rules to establish key problem areas.

The most significant problem area, a factor in 27 of the 30 cases, was insufficient instrument monitoring. Consideration of the flight parameters and information available to the flight crew at the time of the incidents showed that lack of awareness of both rate of descent and altitude were the critical elements for these types of cases. Thus the information to prevent these incidents was available to the flight crew but not assimilated. This situation is associated with excessive external monitoring in conditions of poor visibility, in particular, degraded or non-existent horizon and surface textural cues.

In the event of a flight crew finding themselves in conditions with poor visibility whilst undertaking visual contact flight, two approaches were considered to be useful in assisting them:

- To provide an artificial horizon within the pilot's field of view, whilst he is viewing external references.
- By monitoring flight parameters with relation to surrounding terrain such that relevant warnings can be given to the crew of potentially hazardous situations.

An intelligent flight path monitor, which considers both the aircraft's state and its position relative to the outside world, was the best potential solution (i.e. it addressed most problems) in 16 of the 30 cases. Automatic Flight Path Control was deemed to be the best solution for 4 cases with the remaining 10 being best addressed by adoption of a simple helmet mounted display with head tracking to include horizon information. These solutions were the only 3 out of the 71 proposed that were judged best solutions for individual cases.

By considering all problems of all cases, the intelligent flight path monitor addressed 44% of all problems with the simple helmet comprising a horizon line display addressing 35%. Applying these 2 technologies together it was found that a relatively simple helmet mounted display with an overlaid horizon, coupled with an intelligent flight path monitor, addressed 77% of all problems encountered across the 30 accidents and incidents considered. On a case by case basis this pairing also proved the best combination in 22 of the 30 cases considered.

Special consideration was given to correlation of airspeed with both ground speed and rate of descent; the latter being critical in avoiding the vortex ring state. In the 8 cases where lack of knowledge of airspeed was a factor the airspeed was below 40 knots; a flight regime in which airspeed measurement is unreliable. Thus before devising techniques to benefit the cases in which knowledge of, or correlation of, airspeed with other parameters was important, a reliable means of measuring low airspeeds must be developed.

The quantification of benefit in this study related purely to the safety issues associated with each of the individual cases i.e. the number of accidents that could have been prevented. No attempt has been made to assess cost (in terms of acquisition and operating cost, mass, ease of fit and availability) against benefit (i.e.

lives and aircraft saved). Development of the database, combined with an extension of the analysis, would allow this assessment.

The database centred method devised for this study proved to be an effective tool for analysing helicopter surface collision occurrences and formulating functional requirements for systems to prevent such accidents occurring in the future. This database, as it stands, is a useful source of reference and can be built upon by the addition of further accidents/incidents. Additional potential solutions may also be added. It also has the potential, with suitable development, to encompass different classes of accidents and further problems.

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## 8 LIST OF ACRONYMS

| | |
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| AAIB | Air Accident Investigation Branch |
| ADREP | Accident Data Reporting and Entry Procedure |
| AFCS | Automatic Flight Control System |
| AGL | Above Ground Level |
| ASL | Above Sea Level |
| ATC | Air Traffic Control |
| AVAD | Automatic Voice Alerting Device |
| CAA | Civil Aviation Authority |
| CFIT | Controlled Flight into Terrain |
| CRT | Cathode Ray Tube |
| DH | Decision Height |
| EFIS | Electronic Flight Instrument System |
| GCAS | Ground Collision Avoidance System |
| GPS | Global Positioning System |
| GPWS | Ground Proximity Warning System |
| HMD | Helmet Mounted Display |
| HUD | Head Up Display |
| ICAO | International Civil Aviation Organisation |
| IFR | Instrument Flight Rules |
| ILS | Instrument Landing System |
| IMC | Instrument Meteorological Conditions |
| JAA | Joint Aviation Authorities |
| LCD | Liquid Crystal Display |
| MOR | Mandatory Occurrence Reporting |
| NTSB | National Transportation Safety Board |
| SAR | Search and Rescue |
| VCF | Visual Contact Flight |
| VFR | Visual Flight Rules |
| $V_{MIN\ IMC}$ | Minimum Indicated Airspeed in IMC |
| WAAS | World Airline Accident Summary |