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RESEARCH ON OFFSHORE HELIDECK ENVIRONMENTAL ISSUES

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Joint CAA/HSE Foreword

The research reported in this paper was funded by the Safety Regulation Group of the UK Civil Aviation Authority and the Offshore Safety Division of the UK Health & Safety Executive, and was performed by BMT Fluid Mechanics Limited.

Since offshore helidecks first became operational, the Industry has become increasingly aware of the potential problems of structure-induced turbulence, down draughting, and hot gas plumes generated by turbines and flares. Their effects at individual installations are assessed by means of wind tunnel testing and/or computational fluid dynamics (CFD) modelling and modifications to the platform design are made where required. In the event that the limits established in the design guidance material (CAP 437 – Offshore Helicopter Landing Areas – Guidance on Standards) cannot be fully met, appropriate operating limits are imposed which may subsequently be refined based on in-service experience.

It was recognised, however, that the helideck environmental design guidance material contained in the original (September 1981) edition of CAP 437 was somewhat limited in its quality and scope due to the lack of appropriate technical knowledge at that time. In addition, this subject had been identified for attention in the Report of the Helicopter Human Factors Working Group, published as CAA Paper 87007 (Recommendation 4.2.4). Studies subsequently instigated by both CAA and HSE were inconclusive and, in response to an AAIB recommendation following the heavy landing on the Claymore Accommodation Platform on 18 August 1995 (Recommendation 96-1 in AAIB Bulletin No. 3/96), CAA and HSE jointly committed to the new top-down review reported in this paper.

The CAA and HSE fully support the conclusions of this study and a number of the recommendations have already been actioned as indicated in the footnotes; where applicable, resulting changes to CAP 437 have been incorporated in the Third Edition issued in October 1998. In addition, a turbulence ‘event’ is being developed for inclusion in the analysis software associated with the helicopter operational monitoring trial currently underway with Bristow Helicopters (ref. Section 10.2 (ii)), a Joint Industry Project to produce a helideck design guide has been instigated (ref. Section 10.3 (i)), and HSE have issued Safety Notice 4/99, ‘Offshore Helideck Design and Operation’, drawing duty holders’ attention to the research findings and advising on the actions required (ref. Section 10.3 (ii) & (iii)).

Executive Summary

This report presents the findings of a study commissioned by the Safety Regulation Group of the Civil Aviation Authority (CAA) and the Offshore Safety Division of the Health and Safety Executive (HSE), under CAA Contract No. 154/SRG/R&AD.

Four principal objectives were set by the CAA in the original specification for the work. These were:

(i) To establish the nature and extent of the environmental problems associated with operating to helidecks on offshore platforms.

(ii) To review the 'state-of-the-art' in relation to the techniques and technology that could be deployed to mitigate the identified problems.

(iii) To plan a course of short, medium and long-term actions to address the problems associated with the offshore helideck environment.

(iv) To improve the quality and scope of the guidance material contained in CAP 437 (Offshore helicopter landing areas: a guide to criteria, recommended minimum standards and best practise [9]).

In addressing these issues, the methodology has been to seek the best independent specialist advice and opinions available. Some of this has been drawn from sources close to the day-to-day operation of helicopters to offshore installations but, where appropriate, other specialist input has been sought. These various sources have produced a series of technical reports which have been discussed by a steering group made up principally of representatives of CAA and HSE. Extracts from these reports form a substantial part of this final report.

The principal sources of environmental hazard are identified as vertical wind components, local ambient temperature rise and turbulence. The greatest risk to helicopter operations is judged to be at the point where the helicopter arrives over the helideck and is required to hover prior to touchdown. To date, there have been no serious accidents due to environmental causes which have resulted in injury or loss of life. A 'heavy landing' on the Claymore Accommodation Platform helideck in 1995 has, however, highlighted the potential for such an accident.

A key element of the report is the link that has been established between helicopter performance and environmental disturbances involving either vertical wind flows or changes in ambient temperature. In due course, and with further work, it is expected that it will be possible to establish a corresponding link between helicopter response and turbulence.

The report reviews the sources of hazard and the extent to which they are dealt with in CAP 437. A number of limitations and difficulties in application have been identified which is, perhaps, not surprising considering that the environmental criteria contained in CAP 437 were originally framed over 17 years ago.

Probably the most serious limitation is the lack of any quantitative limitation on an acceptable level of turbulence. This is particularly significant in that the problems most frequently reported by pilots are those involving handling difficulties which are almost

invariably associated with turbulence. It has been noted, however, that pilots use the term 'turbulence' in a generic sense to describe any non-steady disturbance. In some cases this could equally well be caused by non-steady temperature effects due, for example, to the pilot approaching too closely to a hot gas turbine exhaust plume which can produce changes in lift similar to those produced by changes in vertical wind speed (turbulence). In this report, the term turbulence refers to the disturbed airflow downwind of an obstruction which will have components in the vertical, longitudinal and lateral directions.

The origin of the criterion for vertical wind speed currently included in CAP 437 is obscure, whilst the ambient temperature rise is believed to derive from the temperature resolution of helicopter flight manual WAT charts. The review of helicopter performance and handling has enabled both of these effects to be quantified in terms of a key helicopter performance-related parameter, namely the hover/thrust margin. On this basis, it has been possible to establish both a rationale for the current CAP 437 environmental criteria, and a possible means for assessing the impact of any departure from them.

Key issues of design and safety are dealt with in the final section of the report where the role of CAP 437 is reviewed against the wider background of the safety of helicopter operations.

A significant number of recommendations have been identified in the course of this study. These have been classified under headings of short, medium and longer-term actions and are to be found in Section 10 on page 79.

Finally it should be noted that, whilst this research project was in progress and various draft recommendations were being discussed and promulgated, a number of the recommended actions were quickly set in motion by CAA and HSE. These are identified by a series of footnotes in the relevant sections of the report. One key example of this is a further revision of CAP 437 issued during the project and dated October 1998, which incorporates a number of this report's recommendations. In this report the majority of references to CAP 437 are to the 1993 version. However, footnotes have been added to indicate where relevant changes have been made in the latest (October 1998) revision.

Acknowledgement

BMT acknowledges the contribution to this research study made by the following in the form of a series of state-of-the-art reports, extracts from which make up a substantial part of this final report:

Mr A. J. Burt – John Burt Associates Limited.
Report on Operational Procedures and Practices.

Dr M. E. Davies and Mr R. E. Whitbread – BMT Fluid Mechanics Limited.
Environmental Hazards to Offshore Helicopter Operations.

Mr A. Manning, Dr G. Padfield, Mr G. Dadd, Mrs H. Maycroft and Dr M. Ward – DERA.
Reports on Helicopter Performance and Control.

Mr R. E. Whitbread – BMT Fluid Mechanics Limited
CAP 437: Recommendations for Revisions to the Environmental Criteria

These reports were discussed at a series of progress meetings by a steering group with the following membership:

Mr D. Howson – CAA
Mr J. Hopson – CAA
Mr K. Dodson – CAA
Mr R. Miles – HSE
Mr S. Rowe – BMT
Dr S. Coleman – BMT
Mr R. Whitbread – BMT
Mr A Manning – DERA
Mr A J Burt – JBAL

Glossary of Terms/Abbreviations

AAIB	– Air Accident Investigation Branch
AEO	– All engines operating
AERAD Guide	– Offshore installation details supplied by Aerad
ANO	– Air Navigation Order
AOC	– Air operator certificate
BHAB	– British Helicopter Advisory Board
BMT	– British Maritime Technology
BROA	– British Rig Owners' Association
CAA	– Civil Aviation Authority
CAP 437	– Offshore Helicopter Landing Areas: A Guide to Criteria, Recommended Minimum Standards and Best Practice – published by UK CAA
DEn	– Department of Energy
DERA	– Defence Evaluation and Research Agency
DRA	– Defence Research Agency
DVE	– Degraded visual environment
FDR	– Flight data recorder
GPS	– Global positioning system
HUMS	– Health and usage monitoring system
HSE	– Health and Safety Executive
HLO	– Helicopter landing officer
HORG	– Helicopter offshore route guide
Hover/Thrust Margin	– Thrust margin available for helicopter at hover
IADC	– International Association of Drilling Contractors
IAS	– Indicated air speed
ICAO	– International Civil Aviation Organisation
ISO	– International Standards Organisation
IVLL	– Installation/Vessel Limitations List
LDP	– Landing decision point
LED	– Light emitting diode
LFL	– Lower flammable limit
LIDAR	– Light Detection and Ranging
MAUW	– Maximum all-up weight
MOR	– Mandatory occurrence report
MTE	– Mission task element
OEI	– One engine inoperative
OIM	– Offshore installation manager
PAX	– Passengers
SDD	– Safety Data Department (CAA)
SHOL	– Ship/helicopter operating limits
SRG	– Safety Regulation Group (CAA)
TDP	– Take-off decision point
UCE	– Useable cue environment
UKCS	– UK Continental Shelf
UKOOA	– UK Offshore Operators Association
WAT Chart	– Weight/altitude/temperature data for helicopter operations

Contents

1 INTRODUCTION

1.1 Background and Rationale

A key factor in the logistics of offshore oil and gas operations is the ability of helicopters to transport personnel and supplies on a regular basis to platforms which can be a considerable distance from land. UKCS offshore helicopter operations for the period 1973 to 1996 totalled over 5 million sectors flown involving over 2 million flying hours. Up to 1994 (when helicopter operator annual reporting requirements changed), a total of over 32 million passengers had been carried.

Since 1976 there have been 12 fatal accidents associated with UKCS offshore operations which have accounted for a total of 92 lives. In view of the hostile environment, the distances flown and the fact that some operations take place at night, this is considered to be a good safety record. For the period in question, there have been just three accidents in the immediate vicinity of an offshore installation with a total of 18 fatalities – see [1][1], [2] & [3].

In 1995 an accident occurred on the Claymore Accommodation Platform [4] which, although it did not involve any fatalities or serious injuries, did highlight the need to reassess the environmental hazard to helicopters operating in close proximity to offshore installations. The features of the accident which have given rise to concern relate to an uncontrollable descent immediately above the landing area resulting in a heavy landing and extensive damage to the helicopter. The precise cause has not so far been positively identified, but it is most probable that the captain inadvertently flew into a plume of combustion products from a gas turbine unit operating on the bridge-linked production platform.

Pilots are very well aware of the disturbed air flows which can occur in the vicinity of offshore installations and have learnt from experience what to expect. It is significant therefore that the Claymore accident involved a senior captain. In a recent survey of pilots carried out for the CAA [5], the principal safety hazard and source of highest workload was cited as turbulence within the wake region downwind of an installation.

The safety of helicopter operations is of paramount importance and was the subject of a report issued by the CAA in 1995 [6]. The emphasis in this report, however, was on the survivability of passengers and crew in the event of a helicopter coming down in the sea. For this reason, it was principally concerned with what was referred to as the 'safety and survival system' which included all aspects of crew and passenger training, safety equipment, ditching and crash scenarios.

Over recent years much attention has been focused on the need to improve helicopter airworthiness, and significant progress has been made through measures such as the introduction of Health and Usage Monitoring (HUM) systems. Approximately equal numbers of accidents are attributable to operational and airworthiness causes [7] so that any improvement in either area should represent a significant increase in safety.

[1] References are to be found in Section 11 on page 83. There is also a comprehensive bibliography in Annex 2.

A study commissioned by the CAA [8] examined the feasibility of applying operational monitoring techniques on a routine basis to offshore helicopter operations. Such techniques provide continuous operational quality control with timely feedback of non-standard practices, and produces hard information for the evaluation and improvement of procedures. Such information could prove invaluable as a means of improving operating procedures in close proximity to offshore installations.

The current study examines another facet of the safety issue. It is concerned with identifying the unexpected environmental disturbances referred to above, and ensuring that both the risk and consequences of such an occurrence are reduced to a minimum.

At present, the principal instrument available which explicitly imposes an obligation on the platform operator to minimise the occurrence of adverse environmental conditions for helicopters is CAP 437 [9]. This includes a section on '*Air Turbulence and Temperature Gradient*' (Reproduced as Annex 1) which includes two criteria that platform designers are required to address. These criteria were first introduced in 1981 [10] and have remained substantially unchanged for the past 17 years. In that time, considerable experience in the modelling of environmental wind flows around offshore installations has indicated that the current criteria need to be reviewed and possibly revised.

However, it is important to note that, whilst this research project was in progress and various draft recommendations were being discussed and promulgated, a number of the recommended actions were quickly set in motion by CAA and HSE. These are identified by a series of footnotes in relevant sections of the report. One key example of this is a further revision of CAP 437 [11] issued during the project and dated October 1998, which incorporates a number of this project's recommendations. In this report the majority of references to CAP 437 are therefore to the 1993 version [9] However, footnotes have been added to indicate where relevant changes have been made in the latest October 1998 revision.

1.2 Aims and Objectives

A recent report [5] has identified turbulence around offshore installations as a major source of pilot workload which, coupled with the accident involving the Claymore Accommodation Platform [4], has focused attention on environmental hazards facing helicopters operating in close proximity to offshore installations. The response of CAA's Safety Regulation Group and the HSE's Offshore Safety Division has been to commission this research study with the aim of identifying what steps can be taken to minimise the risks to the safety of offshore helicopter operations.

The basic objective of the study as specified was 'to establish the technologies and techniques which could potentially be used to either reduce the environmental hazards, improve their control, or mitigate their effects'. In addition, consideration was to be given to what changes might be made to CAP 437 [9] to improve standards for offshore helideck design.

The ultimate aim was to provide support for a strategy for improving the safety of helicopter operations by proposing short, medium and longer-term actions in which the rôles and responsibilities of the platform designer, the platform operator, the helicopter operator and the regulators are clearly defined.

1.3 Methodology

The approach adopted involved the identification of a series of key topic areas with invitations to acknowledged specialists to contribute 'state-of-the-art' reports with clearly defined objectives.

Four key topic areas were identified at the outset:

(i) A review of practices and procedures currently adopted for offshore helicopter operations to ensure that the experience of the operators and, more particularly the pilots, was fully taken into account (see Section 3).

(ii) The sources and nature of different types of environmental hazard to be identified (see Section 4).

(iii) An assessment of the response of helicopters to various forms of environmental disturbance (see Section 5).

(iv) Finally, it was recognised that the content of CAP 437 needed to be examined to determine whether there was scope for change or additions to the current environmental criteria (see Section 6).

2 THE NATURE AND EXTENT OF THE PROBLEM

The initial phase of this study involved a review of published literature with the aim of gathering as much information as possible from previous studies and investigations. Relatively little is available in the open literature but a number of specialised studies have been made in the past few years, many of which have been sponsored by the CAA. This section is therefore based mainly on such material together with information obtained from accident and incident reports issued by the Air Accident Investigation Branch (AAIB).

2.1 General Literature Review

Searches were conducted of a number of databases using relevant key words such as helicopter, offshore and environment. The results were disappointing in that only seven references were obtained from DERA's own database, six from Marine Technology Abstracts run by BMT and eleven from other sources. A complete listing of all the references obtained for this study are contained in Annex 2.

A number of publications available in the open literature were also identified. These have provided useful information relating to helicopter operations and to safety and survival in particular, but have contributed little more than general background to this particular research project. For completeness, these references have also been included in Annex 2.

The most significant information has come from a limited number of sources namely:

(i) The accident and incident reports issued by the Air Accident Investigation Branch (AAIB) based at Farnborough.

(ii) Two CAA reports issued in 1997 entitled 'Helicopter operational Monitoring Project' and 'A Questionnaire Survey of Workload and Safety Hazards Associated with North Sea and Irish Sea Helicopter Operations'.

(iii) An unpublished CAA report dated 1994 entitled 'A Study of Helideck Risks'.

2.2 Accident and Incident Reports

Air accidents to both fixed-wing aircraft and helicopters are the subject of investigation in accordance with the Civil Aviation (Investigation of Air Accidents) Regulations 1996. Reports are prepared and issued by the Air Accident Investigation Branch (AAIB). The more serious accidents and incidents involve very detailed investigation, the results of which may be published as individual Aircraft Accident or Incident Reports. In cases where the investigation can be less detailed, the results are published in the AAIB Bulletin which is issued monthly. A listing of relevant AAIB reports and bulletins is included in Annex 2.

The following is a brief review of the five principal reports listed in Annex 2 (see Section 1 – Accident and Incident Reports).

(i) **Brent Spar: 25th July 1990**

The tail rotor clipped the top of the 'A' frame of the crane whilst the helicopter was hovering prior to landing. The resulting crash was followed by the helicopter falling into the sea with six fatalities.

Wind conditions were very light, and there do not appear to have been any environmental factors involved.

(ii) **Cormorant 'A': 14th March 1992**

This was a flight involving the transfer of passengers from Cormorant 'A' to a nearby flotel. After take-off in winds gusting to 60 knots, the pilot turned downwind, and in the process lost air speed and height. Application of maximum power failed to prevent the helicopter crashing into the sea with 11 fatalities.

Although wind speeds were close to the limit for helicopter operations, take-off and climb-away were completed without problem. In turning downwind, the pilot failed to retain sufficient airspeed to maintain level flight and hit the sea some 500 m from the platform.

There is no suggestion that the local wind environment around the platform was a contributory factor.

(iii) **Diving Support Vessel 'Mayo': 18th April 1992**

This flight involved a landing on a helideck located over the bow of the vessel which had turned downwind to allow an into-wind landing with the helicopter facing aft. Deck motion and wind speeds were within limits up to the point of touchdown.

A sudden unexpected motion of the vessel just after landing caused the helicopter to move backwards across the deck. At the same time the rotor blade dipped and struck the HLO. The helicopter then took off to avoid further problems.

Wind speeds up to 45 knots were within limits and the accident was due to excessive and unexpected roll motion of the helideck. Wave motion was therefore the primary cause of this accident.

(iv) **Claymore Accommodation Platform: 18th August 1995**

This flight took place shortly after the Claymore Accommodation Platform helideck had been cleared for service. After a normal into-wind approach, the pilot experienced an uncontrollable rate of descent which resulted in a heavy impact with the deck. Fortunately, there were no casualties.

Environmental factors were almost certainly the primary cause of this accident. Winds were light (3–5 knots) and the key feature of the report is that the crew were aware of being 'engulfed in the downwind emissions of the flare.'

A close examination of all the factors involved suggests that the crew may have been mistaken in identifying the flare as the source of the emission. It is much more likely that the plume from the gas turbine exhaust on the Claymore Production Platform was the cause of the problem.

(v) **Phillips Audrey A 49/11a Satellite Platform: 31st December 1996**

During an approach to this unmanned platform, a helicopter pilot noticed a trail of vapour spreading downwind from the installation. The time was 09:15 hrs and visibility was reckoned to be five nautical miles. The situation was reported to the satellite OIM, the flight was aborted, and the installation shut down. Subsequent investigation revealed a 10 mm x 5 mm hole in a choke spool.

Fortunately there were no serious consequences. Had the flight been made at night or in poor visibility, then the outcome might have been different.

2.3 Helideck Risk Study

This report [12], extracts from which are reproduced at Annex 3, was issued in 1994 and was based on a survey of opinions drawn from a cross-section of interests involved either directly or indirectly with offshore helicopter operations. The declared objective of creating and analysing a detailed and comprehensive database containing information on helideck related incidents and accidents was unfortunately not achieved due to difficulties in gaining access to key information.

No firm conclusions were drawn although a number of topics were identified as warranting further attention.

These included:

(i) Human Factors

Pilot workload, cockpit ergonomics, visual cues for approach guidance (e.g. relating to identifying the helideck position in poor visibility or at night), *information flow* (e.g. rig status, changes in weather), piloting skills and incorrect loading.

(ii) Helideck Features

Turbulence, unscheduled changes of offshore installations and their surroundings, rig identification, helideck and rig lighting.

(iiii) Helideck Procedures

Information flow (e.g. rig status, weather/loading changes), ground and in-flight paper work and the *feasibility of standardising more approaches to rigs* (including the role of approach aids).

(iv) Helicopter Design

Handling qualities, normal and after stabilisation/control system failure and thrust margins.

The topics shown in italics have a bearing on the present study, many of which are dealt with later in this report.

2.4 Helicopter Operational Monitoring Project

This report [8] was prepared jointly by CAA and Stewart Hughes Ltd. It focuses on the application of operational monitoring techniques to the routine analysis of flight data recorder (FDR) data to detect deviations from normal, expected or flight manual practice. This is a well-established technique for fixed-wing aircraft and provides continuous operational quality control with timely feedback of sub-standard practices, and produces hard information for the evaluation and improvement of procedures.

Positive experience with fixed-wing FDR operational monitoring programmes resulted in a decision to investigate the application of the same general techniques to helicopter operations. The overall conclusion drawn by the report was that such techniques could readily be applied to offshore helicopter operations, and should make a positive contribution to the safety of such operations.

The application to the present study is seen in terms of establishing a routine system for monitoring the handling of helicopters in close proximity to offshore installations to detect situations where excessive control or power corrections are made by pilots to maintain a chosen flight path. The value of the technique will be in the ability to routinely monitor the effectiveness of any measures introduced to reduce safety hazards. In the context of the present study, this would relate to minimising the frequency and severity of environmental occurrences in close proximity to offshore installations.

2.5 Pilot Survey of Workload and Safety Hazards

This study [5] was carried out by the Defence Evaluation Research Agency (DERA) Centre for Human Sciences to establish whether, and under what circumstances, the workload on pilots imposed by in-flight paperwork was excessive. The study was conducted as a survey of pilot responses to an extensive series of questions regarding the sources and significance of various forms of workload. Pilots were asked to rate how often a particular aspect of their operational duties contributed to a safety hazard. Of the 13 key topics listed, 'filling in paperwork' was rated only as the third most hazardous behind 'weather conditions' at number two, with 'turbulence around platforms' topping the list.

A summary of the responses to the question 'Does turbulence around platforms cause you a high workload or a safety hazard?' is reproduced at Annex 3. The result of this survey has had particular significance as far as this current study is concerned.

2.6 Survey of Operational Difficulties and Restrictions Imposed on Helicopters Operating to Offshore Oil/Gas Facilities in the North Sea

This report, prepared by Offshore Environmental Services in 1987 [13], was the outcome of the first phase of a project sponsored by the CAA and DEn. Although it presented a useful review of the situation at the time, the report was mainly targeted on obtaining funding from the Industry for further research. Due to the downturn in the price of oil this was not forthcoming and the project as originally proposed was never completed.

The report itself consists of summary details of installations operating at the time, together with warnings to pilots relating to the existence of turbulence and/or temperature rise due to gas turbine exhaust.

2.7 Wind-Flow Modelling Studies

Wind-flow modelling studies, generally carried out at the design stage for a new installation, have been the principal means of evaluating environmental wind effects in the expectation of achieving compliance with the guidance of CAP 437. Over the past 20 years, several hundred such studies have been commissioned with the result that there is a considerable volume of literature available in the form of technical reports, many of which have originated from BMT Fluid Mechanics Limited [14] [15].

Each report presents the results of a fairly standard set of wind-tunnel tests which include an evaluation of both the wind-flow environment over the helideck, and the increase in ambient temperature resulting from a hot gas turbine exhaust plume traversing the helideck area. In most cases some form of remedial treatment will have been needed to achieve as near a compliant situation as possible within the constraints imposed by the design team.

A number of examples of reports issued by BMT are listed in Annex 2.

2.8 Wind Flow over Naval Flight Decks

A review of naval helicopter experience produced by DERA specifically for this study covered 130 events involving accidents to helicopters flying routine missions to and from naval ships for the period 1987–97. Of these, only 17 were considered relevant to the present study and only in 5 cases was 'turbulence from superstructure' cited as a factor.

No particular conclusions were drawn from this review except that pilot error and turbulence were loosely linked, indicating that high workloads due to turbulence increase the risk of a pilot making an error of judgement despite the high level of skill normally associated with helicopter flying. This same conclusion will apply to offshore helicopter operations although the levels of turbulence encountered are likely to be less than those associated with naval operations due, both to the better exposure of offshore helidecks, and the fact that wind speeds over naval helidecks are generally increased by the forward speed of the ship.

The most severe effects of the airwake over a naval flight deck are mitigated to some extent by the fact that helicopter operations are subject to restrictions (often quite onerous) imposed by the Ship Helicopter Operating Limits (SHOLs). These are established by test pilots during 1st-of-class trials and represent safe limits on wind speed and direction for which normal service operations are permitted.

There also exists an MoD Design Guide for naval flightdecks [16] which identifies points of good design practice which should minimise adverse environmental effects.

The lack of either an equivalent design guide for offshore helidecks or anything equivalent to the SHOL system, means that any transfer across from naval experience to the offshore situation is of limited value.

3 OFFSHORE HELICOPTER OPERATIONS

The first phase of the study was designed to establish a broad understanding of the impact of environmental factors on helicopter operations with particular reference to the actual problems faced by pilots. It was recognised at the outset that responsibility for the safety of helicopter operations rests very much with the pilot and his ability to deal with unexpected or emergency situations which inevitably arise from time to time.

The focus throughout the study has been on the hazards associated with landing and take-off from offshore installations and, more particularly, with those hazards arising from disturbances to the wind-flow and temperature environment in the immediate vicinity of the helideck. The aim at this early stage has been to establish just how much of a problem exists and what steps might be taken by way of mitigation.

This section of the report has been prepared by John Burt Associates Limited in consultation with Bristow Helicopters Limited and Captain Adrian Thomas, the current chairman of the BHAB Helideck Sub-Committee. This Committee has responsibility for evaluating new and existing UKCS helidecks in order to set appropriate operating limitations. The limitations imposed are promulgated in the Installation/Vessel Limitations List (IVLL), which covers warnings to pilots of potential safety hazards, and includes fairly frequent references to 'turbulence'. Further background is to be found in [17].

3.1 Operational Procedures and Practices

Offshore flight operations are a highly complex and specialised process. It requires high levels of training, competence and skill to plan a flight, land and take-off from an offshore installation, and to consistently execute the task efficiently and safely under 'normal', good weather flying conditions. Introducing adverse weather to the task (e.g. poor visibility), night flying or other predictable and/or unpredictable factors that can be routinely found in and around the environs of an offshore installation, can stretch the skills of flight crews to the human limit.

Fixed-wing flying (public transport) operations to and from runways at onshore airfields usually enjoy plenty of space, well defined obstruction clearances, efficient air traffic control, sophisticated landing aids, good meteorological information and standard procedures for approach, landing and take-off. However, offshore helicopter crews have relatively little technology and fairly limited information to assist them when they commence their final approach for a landing at an offshore landing site. It is much the same when taking-off for the return flight. Despite the many advances in aircraft technology, navigation, landing and communications aids in recent years, there are currently no reliable and effective electronic landing aids available for use on offshore installations. Therefore, offshore helicopter crews have to rely heavily on their acquired skills and experience when approaching, landing and taking-off from offshore installations.

It is not necessary or appropriate to review the whole scope of helicopter flying in this study. However, it is essential to address two key topics concerning flight crew activities that are performed within the offshore flight operations process. These are:

- Pilot information, and
- Approach, landing and take-off manoeuvres.

3.2 Information Available to Pilots

During the flight planning stage, it is vital for the flight crew to have access to as much relevant information about the offshore landing site as possible. For UKCS offshore flights this will include:

- Meteorological information
- Installation/Vessel Limitations List (IVLL)
- AERAD Plate and /or Route Guide

3.2.1 *Meteorological information*

At base, weather information is obtained by the flight crew in the form of a general regional meteorological forecast, an area forecast covering the offshore destination (if available), and an actual weather report from the destination installation. The weather information will include temperature, pressure, cloud base, visibility and wind conditions. Temperature and pressure will be used in conjunction with the aircraft performance graphs to calculate the power available and acceptable payload for take-off and landing.

The aircraft performance graphs are found in the Aircraft Flight Manual and are developed by the helicopter manufacturer and then approved by the Civil Aviation Authority as part of the initial certification process for a specified aircraft type. These graphs are essential to the pilot because they give the aircraft weight for his take-off procedures and, in turn, this relates to the OEI (One Engine Inoperative) conditions that a pilot must be acutely aware of at all times during the critical flight phases (e.g. approach, landing and take-off). Nowadays, computer generated performance graphs are generally available to pilots working for the major offshore helicopter operators, thus, to some extent reducing workload during flight planning.

Free and surface wind conditions (actuals) for the installation location are also required by the flight crew for planning and safely executing approach, landing and take-off manoeuvres at the installation. During flight planning, the wind conditions will be checked against the IVLL to establish whether they occur in ‘turbulent sectors’ of the destination installation. If adverse winds occur outside the ‘turbulent sectors’ the flight can generally operate within normal aircraft Flight Manual wind velocity and payload limitations. If adverse winds occur within the ‘turbulent sectors’, reference to the IVLL will specify additional wind velocity and payload limitations (for each different helicopter type), imposed by BHAB for the destination installation.

It can reasonably be stated that weather information received by pilots from official meteorological forecasting sources is generally of good quality. Recent years have seen significant improvements in weather forecasts due, mainly, to the sophisticated technology advances used for acquiring and processing weather data. As a result, the interpretations by weather specialists have become more accurate.

The quality of weather information provided from offshore installations, however, is variable. Instrumentation is often limited and fairly basic, and is often poorly sited and calibrated leading to fundamental errors in reporting. Also, the readings and observations that are used in the *actual* weather reports for a given installation rely entirely on the basic knowledge of personnel who usually lack specialist meteorological skills. However, the situation is improving in this respect with the introduction and use of sophisticated, ‘on line’, automated weather instrumentation packages.

3.2.2 *Installation/Vessel Limitations List (IVLL)*

The Installation/Vessel Limitation List (IVLL) is issued by the British Helicopter Advisory Board (BHAB). It is the only official document that is currently in place to promulgate details of offshore helidecks with non-compliances which require operational limitations. For the purposes of this section reference to non-compliance concern the physical characteristics criteria contained in CAP 437 which may provide 'turbulence' generation or gaseous emissions.

Non-compliances can originate from two sources:–

(i) In the first instance, helideck designs are given an approval by the CAA in accordance with the requirements laid down in CAP 437 [2]. Those helidecks with non-compliances, that in the Authority's opinion may require operational limitations, are passed on to the BHAB Helideck Sub Committee for review and the setting of appropriate limitations. Account is also taken of any significant physical (e.g. 5:1) infringements at the installation. Having taken the committee's comments into account, the CAA then issues an approval letter listing the non-compliances and the appropriate limitations. These limitations are then published in the IVLL.

(ii) The second source originates from flight crews and focuses mainly on operational helideck/installation performance, rather than physical obstructions. When first starting operations to a new offshore installation, flight crews are asked to submit Turbulence Report Forms for review by the BHAB Helideck Sub-Committee. These reports allow an operational assessment of the installation to be made in order to validate initial limitations that may have already been applied. They also allow limitations to be modified on the basis of ongoing experience. Setting these flight operating limitations can take from a couple of weeks to several months. The time taken is dependent upon the frequency of weather patterns encountered and obtaining sufficient pilot reports.

The process for setting flight operating limitations for turbulence around offshore installations appears to be almost entirely subjective and is rarely, if ever, the direct result of technical design input. Initially, during the installation design verification process, CAA advise the BHAB Helideck Sub-Committee where they consider there are deficiencies in installation design that merit consideration for flight operating limitations. The information at this stage is taken from general arrangement drawings and wind-tunnel test reports submitted for appraisal, in accordance with CAP 437.

Having received this advice from CAA, the BHAB Helideck Sub-Committee initially responds by advising the flight crews of potential problems and then undertaking an operational 'field' evaluation of the turbulent environment to validate the final flight operations limitations to be applied. This work is normally done without reference to the findings and recommendations given in specialist design reports (e.g. wind-tunnel tests) for the installation. Historically, the reasons for pilots largely ignoring these technical reports are difficulties in making a practical interpretation from the

[2] Since 1st December 1998 it has been the responsibility of the BHAB Helideck Sub-committee to issue Helideck Certificates following inspection, and to promulgate appropriate limitations in the IVLL. The IVLL is now accepted as a part of all offshore helicopter operators' Operations Manuals.

results and lack of confidence in the validity of simulations and thus the associated results.

The Turbulence Report Form is the primary mechanism the BHAB Helideck Sub-Committee use to obtain information about three main effects on the aircraft whilst flying onto an offshore installation. They are:–

- Handling problems
- Turbulence encountered
- Down draught

The scales used to quantify these effects are:

- Nil
- Light
- Moderate
- Severe
- Extreme
- Overshoot required

Completion of Turbulence Report Forms is normally done after the crew have returned to base.

The fact that a BHAB procedure exists which requires this level of reporting supports the position that *turbulence* (generally perceived by flight crews as any effect that causes handling difficulties or aircraft instability) is a serious issue for offshore flight safety.

However, the type and origins of turbulent effects around offshore installations do not appear to get analysed to any great extent by 'line' pilots. Their primary interest is simply, does it exist? If so, how severe is it likely to be for a given wind velocity and where is it going to occur in relation to selected flight paths? This is an interesting point to note because it means that apart from 'downdraughts' (generally considered a function of helideck aerodynamics), there is no requirement to differentiate between induced turbulence from structures, disturbed airflows from the thermal effects of flares and exhausts or combinations of both problems.

This lack of distinction is not because pilots do not know the difference between the various turbulent and thermal effects they may encounter. It is simply attributed to the fact that at the time handling difficulties or aircraft instability occur, an operational 'line' pilot is compelled to focus solely on safe arrival or departure, rather than an in-depth analysis of where the problem has come from.

Therefore, the question that immediately arises is whether it is possible to routinely obtain good operational feedback (qualitative or quantitative) about the individual contributors to turbulence experienced around offshore installations, in order to accurately quantify the actual effects of each individual contributor. Doing so routinely on offshore revenue flights is out of the question. Increasing cockpit workload and potentially increasing crew/passenger exposure during the critical flight phases would be unacceptable. Routine FDR analysis on the other hand, as described in Section 2.4, could be an appropriate compromise which would not interfere with flight operations.

One alternative would be to provide a dedicated aircraft (non revenue) for a series of tests. This would require a well thought out test programme with well defined deliverables and the project would have to be properly managed. The initial problem is justifying the cost of such a programme. Also, from a pilot's perspective, it would be an extremely difficult task to fly when a number of environmental phenomena are present at the same time.

When considering the above situation, the following questions must be answered before proceeding any further:–

(i) Is there real value in obtaining more accurate information about turbulence (qualitative and/or quantitative) than that already provided by the Turbulence Report Form?

An investigation of the turbulence characteristics for several specific installations would be useful in establishing quantitative data.

(ii) Would this improved level of data help with establishing more accurate and more appropriate flight limitations?

Correlation between information obtained for specific installations and corresponding model-test data would enhance confidence in the latter.

(iii) Would the improved data provide a sound basis for validating current model testing simulation procedures and results?

Almost certainly yes.

(iv) Would BHAB, in future, be more inclined to use the results of properly qualified, design simulation reports toward setting initial flight operating limitations?

Again, almost certainly yes.

(v) Are there other options available? For instance, comparing current IVLL limitations (experience based) against simulated data (e.g. wind-tunnel test results) for a selection of installations to establish whether there is reasonable correlation between the modelled and field results.

As a first step, this would be useful in establishing qualitative correlation.

3.2.3 *AERAD Guide and Route Guide*

AERAD Guide

The AERAD Guide is a document which contains information and plates for a complete listing of aerodromes, helidecks, etc. One section is relevant to offshore flight operations, namely the HORG (Helicopter Offshore Route Guide).

An AERAD Plate issued for an offshore helideck is generally a composite, single sheet information document that is produced by the Aerad Organisation for each individual installation. It gives flight crews a dimensioned general arrangement of the installation (elevation) and helideck (plan). Additionally, it provides the installation co-ordinates, aeronautical radio frequencies, critical obstructions and heights, key equipment available on board and sometimes includes notes concerning restricted sectors due to exhaust temperature effects.

Currently, there is a proposal to tie the Aerad Plate to the IVLL. This move, by BHAB, is generally in response to a recommendation made by the AAIB in their report on the S61 accident on the Claymore Accommodation Platform in 1995.

The report recommended that:–

'The BHAB, acting on behalf of the Helicopter Operators, should examine, in co-operation with Aerad (the chart production company), the possibility of publishing approach charts that provide information to crews on the location of turbine exhausts and flare stack emissions in order that commanders are made fully aware of all potential hazards that might affect the performance of their aircraft during approaches, landings and go-arounds to helidecks.

Consideration should also be given, where platforms are located in close proximity to one another, to depicting on one chart the combined installations so that the effects that one platform may have on the adjacent helideck can be more readily assessed by crews.[Recommendation 96-2]'

It is reported that this task is not without its difficulties. Also, there is concern that the Aerad publication process is too slow to ensure the currency of the information.

Route Guide

The 'Route Guide' is a proprietary document used by Bristow Helicopters Limited. Other helicopter operators may use similar documents with similar titles, or, as in the case of British International Helicopters, they rely solely on AERADs supplemented by specific notices about individual offshore installations.

The Bristow Route Guide is essentially a collection of information about a whole range of offshore installations. It includes photographs, drawings, general data and notes, etc. that can be referred to by flight crews to familiarise themselves with an intended destination helideck/installation. Although an unofficial, in-company document, its value should not be underestimated for providing flight crews with good visual references and additional information about an installation. However, it is bulky and, like all documentation, it needs to be kept up to date to be of real value.

3.3 Approach, Landing and Take-Off Manoeuvres

3.3.1 *Standard procedures*

There are standard procedures to be followed by flight crews when approaching, landing and taking-off from installations. These procedures vary between helicopter types to take account of handling characteristics, performance, etc.

The reality is that, due to the large number of environmental variables likely to be encountered around offshore installations and the different levels of familiarity and experience of specific installations, individual pilots will tend to fly the approach and execute a landing and take-off using slight variations to the standard procedure. These variations occur as a natural human response to sometimes extremely difficult flying conditions and are required simply to accommodate the handling pilot's own level of skill and expertise and his perception of the risks surrounding him and his aircraft. Such variations to standard procedures are accepted practice and generally fall within the Captain's ultimate responsibility for ensuring the safety of his aircraft and passengers.

At first, the apparent lack of rigidly applied standard procedures may seem rather odd, particularly when there are standard helicopter approach procedures to naval vessels. These are laid down by the Royal Navy and are conducted in accordance with SHOLs which have been developed as a result of extensive flight trials. The performance characteristics of the aircraft are well known, and are accounted for in the approved operating envelope in terms of relative wind speed and direction over the deck. This envelope will also take into consideration specific characteristics of the ship, for example, downdraughting from the hangar which can result in a significant reduction in the take-off and landing weights permitted. In contrast, civil operations have evolved empirically. Helideck landings and take-offs on Royal Naval vessels are generally executed when the vessel is underway and they are invariably to aft mounted helidecks that are built to generic specifications for specific vessel types (with the exception of aircraft carriers). Military helicopter launch and recovery techniques are also designed and practised primarily for combat situations.

The offshore support helicopter is classed as a non-scheduled, public transport service and flies passengers to a variety of fixed and mobile installations and vessels that are normally anchored on station. Installation/vessel helideck specifications, locations, elevations and other performance influencing factors can vary enormously between installations. Even with a generic type of installation, such as some classes of semi-submersible drilling rigs, there can be marked helideck performance differences between individual rigs. This can be the result of different owners configuring topside arrangements slightly differently to meet their individual operating layout preferences.

The highly variable situation with offshore installation helideck design layouts makes it extremely difficult (even for a highly experienced Chief Pilot) to quantify a standard approach even for a generic installation/helideck design. This makes it highly desirable, if not essential, for a helideck designer to have a good understanding of the needs of the flight crews. To that extent 'textbook' profiles of approach, landing and take-off manoeuvres may give some indication of the procedures and concerns that are in the mind of a pilot when flying to an offshore helideck.

3.3.2 *Approach and landing on fixed installations*

Having completed final approach checks at 5 miles the handling pilot is focused entirely on his approach pattern and landing. This also includes bearing in mind the intended flight path and actions to be taken in the event of an overshoot for whatever reason (e.g. single engine failure). The handling pilot's aim is to make the transition from forward flight into the hover and then arrive over the landing circle to land onto the helideck.

In good weather at, say, 1000 m distant and 500 ft altitude, the pilot will line up into wind and establish a 4° to 6° glide path to bring him onto the helideck. As he approaches the helideck, he will bleed off forward speed and adjust his rate of descent to maintain the approach angle and a minimum of 40 knots IAS until he is committed to make a landing. At the Committal Point he will continue to reduce speed, aiming to pass over the edge of the helideck at a ground speed in the order of 5 – 10 knots, finally bleeding off residual ground speed and height to arrive a few feet above the landing circle at zero ground speed.

All helicopters currently operating offshore on the UKCS are capable of executing a safe approach and landing in zero wind, assuming an engine does not fail. However, if an engine does fail, the headwind component becomes critical because these are not Performance Class 1 operations (i.e. there may be an exposure period when the flight cannot safely be continued in the event of engine failure).

A good headwind component gives additional forward airspeed to provide a margin for recovery in the event of an engine failure. On average, North Sea wind speed is around 15 knots and thus normally provides the necessary margins. However, low or zero wind conditions are critical because the headwind component is either inadequate or absent. Wind speeds above 30 – 35 knots provide a good performance margin, but signal the onset of 'free air' turbulent conditions. Throughout approach and descent manoeuvres the pilot should always aim to keep his power demand below the aircraft single engine power requirement. This should ensure sufficient reserves are available in the event of a single engine failure. Should an engine failure occur prior to the Committal Point for landing, the combination of sufficient airspeed and single engine power are basic requirements for a pilot to recover and climb away in OEI (One Engine Inoperative) flight conditions. If the engine failure occurs after the Committal Point, the pilot is already committed to land and his maximum all up weight (MAUW) should have been previously planned to ensure a safe landing.

During an approach in low or zero wind, too steep and too rapid a descent will require high transient power to recover from a single engine failure. It is also possible to encounter aerodynamic conditions conducive to the onset of vortex ring. Too shallow a descent will require use of more than single engine power demand to arrest the descent for a landing and to avoid the risk of hitting the helideck edge. If higher winds are present during a steep descent and the aircraft is caught in a downdraught prior to helideck arrival, this will also give the same problems and outcome as in zero winds. Too shallow a descent will have the same effect.

Out-of-wind components also have to be taken into account to accommodate variable wind angles across an offshore helideck. Acceptable out-of-wind components for a given MAUW are determined for specific helicopter types in the Flight Manual. For example, the Eurocopter AS332L can accept 17 knots on the beam (90°) at MAUW. At 500 lb below MAUW (equivalent fuel use for half an hour's flying) it can tolerate a 90° cross-wind component of up to 35 knots. However, out-of-wind components are not generally used by helicopter pilots offshore. The preference is to optimise the aircraft's control and performance margins by maintaining a wings level attitude into wind. By doing so, the aircraft is headed into the most favourable winds for the hover and landing. This also means that the helicopter will be well positioned into-wind for the subsequent take-off, unless a wind shift occurs. The precise heading chosen will vary by a few degrees for different pilots, but the ultimate aim is still the same.

The worst case for a pilot are those occasions when he has to approach, land and take-off facing toward the structure of an installation, due to an adverse wind direction with wind flows coming across the structure. In these circumstances, it becomes necessary to commit to a landing further out. Such adverse wind flows require a much steeper approach to the helideck to ensure that a landing can be made should a single engine failure occur after the Committal Point. If a single engine failure occurs prior to the Committal Point, adequate obstruction clearance height is required to safely fly away and achieve an OEI recovery.

3.3.3 *Approach and landing on mobile installations*

The same general considerations apply for approaching and landing on mobile installations as for fixed installations. However, because the pilot also has to consider the helideck motions, the landing manoeuvre requires a slightly different approach profile.

In this case, the pilot will fix a point in space as his decision point for landing (Committal Point). From the Committal Point, he will fly the aircraft to the landing circle. In the event of single engine failure after Committal Point, the handling pilot is already committed to land. If a failure occurs prior to Committal Point, he should be clear of obstructions to overshoot and should have sufficient forward airspeed and altitude to make a safe OEI recovery.

3.3.4 *Take-off manoeuvres*

Following completion of hover checks at say, 10 – 15 ft above the helideck, for a 'normal' take-off profile the pilot should aim to take-off in a dynamic manner ensuring that the helicopter continuously moves from the hover into forward flight. The pilot should select the optimum Rotation Point so as to ensure that the take-off path will continue upwards and away from the helideck with all engines operating (AEO), but minimise the possibility of subsequent height loss and hitting the helideck edge in the event of an engine failure.

The Rotation Point is defined as the point at which a cyclic input has been made initiating a nose-down attitude change to establish forward flight. The Rotation Point varies with helicopter type. In the event of an engine failure being recognised after cyclic input at the Rotation Point, take-off must continue because the helicopter is no longer able to safely reject the take-off and land back on the helideck.

A take-off in adverse wind conditions (with wind flows across the structure) poses greater problems because it requires a significant power demand to climb (in the hover) almost vertically above the helideck out of ground effect (normally up to 25 ft, but can be up to a maximum of 45 ft dependent on aircraft type). The climb, in hover, will usually take the aircraft through turbulence created by the structure, to a point where the helicopter is clear of both turbulence (once clear of any turbulence less power is normally required for continuing the climb) and obstructions, and the pilot can make the transition to forward flight at his Rotation Point. Once forward flight is established the pilot should be able to fly safely clear of the installation.

3.3.5 *Avoidance of environmental hazards*

Specific flight procedures and limitations are applied to some offshore installations where the combined effects of adverse wind flows and the increased temperature effects of exhaust plumes/flares are likely to be present.

There are currently no laid down boundaries for avoiding the effects of gas turbine exhaust plumes or flares. The pilot is generally considered to be clear of the problem until he commences finals at a range of 500 m from the platform.

3.3.6 *Combined operations*

When operating to combined installations the foregoing considerations equally apply to the helideck in use. Normally, because the 210° and the 5:1 obstruction clearance sector requirements come into play, along with induced structural turbulence and other factors (e.g. exhaust plumes), it is normal to seek a compromise solution by nominating one of the helidecks for each wind direction.

3.4 Accident and Incident Reporting

It is important to put the problems caused by adverse environmental effects around offshore installations into context. This is best done by analysing the accidents and incidents that have occurred on or around offshore installations where such effects have contributed to the outcome. This review is confined to those events involving offshore installations on the UKCS.

3.4.1 *Data sources*

In the UK, the primary sources of aircraft accident/incident data and statistics are:–

Civil Aviation Authority – Safety Data Department (SDD)

(i) UK Offshore Helicopter Operations Statistical Reports (Annual)
(ii) Occurrence List – UK Rotary Wing (Monthly)
(iii) World Helicopter Accident Summary (On behalf of ICAO)
(iv) Mandatory Occurrence Reports (MORs)

DETR Air Accident Investigations Branch (AAIB), DERA Farnborough

(i) Accident Bulletin (Monthly)
(ii) Accident Reports (Specific Reportable Accidents)

Helicopter Operators

(i) Accident Statistics including Flying Hours, Sorties, Pax Carried, etc.
(ii) Internal Accident Reports (for Specific Accidents)

3.4.2 *Accident and incident data gathering*

In Section 2.2, summaries are given of five AAIB Reports. The causes attributed to three of these accidents were not directly associated with the environmental situation close to an offshore installation and are not considered relevant to the present study. Of the remaining two occurrences, that which occurred at the Claymore Accommodation Platform in 1995, is relevant and is the only case which has been investigated in detail.

In addition to obtaining AAIB Reports, the occurrence database maintained by CAA's SDD was interrogated for incidents that could be linked to environmental hazards around offshore installations. This exercise yielded 29 officially reported occurrences for the period December 1976 to July 1997.

The 29 occurrence reports were analysed to filter out only those which happened directly (primary cause) or indirectly (secondary cause) as a result of the operating environment in the vicinity of offshore installations. Of these cases, 18 were found to be directly relevant to the present study (see Annex 4).

Reference to Appendices D and E in CAA CS Report 9455, A Study of Helideck Risks [12], also provides further evidence of many helideck-related incidents, some of which may have resulted directly from adverse helideck environs. It should also be noted here that 79 incidents were reported internally within the helicopter operating company in the period 1983 – 89, but only 11 were reported as part of the MOR system. This leads to the suggestion that helicopter incidents involving adverse environments around offshore helidecks could well be understated. This is supported by views expressed in [12] regarding the quality of UKCS offshore helicopter accident/incident reporting.

Some of the problems that impede good offshore helicopter incident analysis are:–

(i) Over the years, offshore UKCS helicopter incident reporting has lacked consistency. However, there has been some improvement in recent years.

(ii) The available databases appear to be at variance with each other.

(iii) MOR reporting for the earlier years is very limited and, currently, some helicopter operators are providing more and better information than others.

(iv) Helicopter operator internal incident reports appear to be much greater in number than MORs suggesting that incident reports are filtered at source. Also, these reports are not generally in the public domain and are difficult to obtain. It is therefore almost impossible to develop a complete and accurate picture.

3.4.3 *Accident and incident analysis*

Over the period 1976 – 1998 (the period for which reasonable accident/incident data is available), there have been no fatalities attributed to offshore helicopter accidents resulting directly or indirectly from adverse helideck environmental conditions.

However, a coarse review and analysis of a wide range of incident reports from various sources clearly shows that a significant number of incidents have occurred on and around offshore installations. In some cases there is scant information for good analysis. Nevertheless, in total, there are approximately 30 incident reports that can be attributed to adverse helideck environmental conditions.

The primary sources for these reports are the CAA – SDD, MOR Database and CS Report 9455 – A study of Helideck Risks [12]. The following is a brief analysis of the 18 occurrence reports contained in Annex 4.

<table>
<tr><th colspan="20">FLIGHT PHASE AT OFFSHORE INSTALLATION</th></tr>
<tr><th colspan="4">APPROACH</th><th colspan="4">LANDING</th><th colspan="4">TAKE-OFF</th><th colspan="4">HOVER</th><th colspan="4">CLIMB</th></tr>
<tr><td colspan="4">5 (27.8%)</td><td colspan="4">9 (50.0%)</td><td colspan="4">2 (11.1%)</td><td colspan="4">2 (11.1%)</td><td colspan="4">0 (0%)</td></tr>
<tr><th colspan="20">PRIMARY CAUSE</th></tr>
<tr><th colspan="5">FLARE/BURNERS</th><th colspan="5">TURBULENCE</th><th colspan="5">EXHAUST PLUMES</th><th colspan="5">PILOT ERROR</th></tr>
<tr><td colspan="5">4 (22.2%)</td><td colspan="5">7 (38.9%)</td><td colspan="5">3 (16.7%)</td><td colspan="5">4 (22.2%)</td></tr>
<tr><th colspan="20">SECONDARY CAUSE</th></tr>
<tr><th colspan="4">FLARE/BURNERS</th><th colspan="4">TURBULENCE</th><th colspan="4">EXHAUST PLUMES</th><th colspan="4">PILOT ERROR</th><th colspan="4">OTHER[3]</th></tr>
<tr><td colspan="4">0 (0%)</td><td colspan="4">9 (50.0%)</td><td colspan="4">2 (11.1%)</td><td colspan="4">3 (16.7%)</td><td colspan="4">4 (22.2%)</td></tr>
<tr><th colspan="20">FAILURE CATEGORY</th></tr>
<tr><th colspan="10">INSTALLATION DESIGN</th><th colspan="10">A/C OPERATIONS</th></tr>
<tr><td colspan="10">12 (66.7%)</td><td colspan="10">6 (33.3%)</td></tr>
</table>

The outcome of this coarse analysis shows that defects in installation design can be cited as the cause for two thirds of the incidents reported. This situation clearly suggests that helideck operability was not properly addressed during the initial design phase of the installations concerned.

Also, entries in the BHAB Installation/Vessel Limitation List (IVLL) support the need for raising awareness about helideck operability issues early in the installation design. A simple count of 375 installations (fixed, mobile, etc.) listed in the IVLLs published for the Northern North Sea in January 1997 and in the Southern North Sea in February 1997 [18] shows the following:

UNRESTRICTED HELIDECKS	RESTRICTED HELIDECKS
96 (25.6%)	279 (74.4%)

Restrictions referred to above include CAA notified non-compliances (e.g. physical obstructions in 210° sector and 5:1 infringements) and limitations/comments arising from flight experience (e.g. turbulent sectors and turbine exhaust effects).

3.4.4 *Unreported occurrences and near misses*

Incident analysis is not complete without making reference to the probable number of potential accidents that may have occurred. In other words, 'near misses'. Whilst few major accidents occur, there are large numbers of reported incidents, and an even larger numbers of unreported occurrences. All have common characteristics – they are inadvertent, possibly life threatening and they happen repeatedly.

To get a better picture of the potential risks that adverse offshore helideck environments might realistically pose to flight safety, there is some merit in looking at accident ratios. With minor modification, the occupational accident and injury ratios (1:29:300) first suggested by Heinrich in 1931 [19], can be used to illustrate the possible relationship between 'near misses' and other categories of reported

[3] Other includes Not Known, Weather Conditions, Not Applicable, etc.

accidents and incidents. If the Heinrich ratios are applicable, then it is reasonable to conclude that the flying risk associated with adverse environmental conditions in and around UKCS offshore installations is probably well understated.

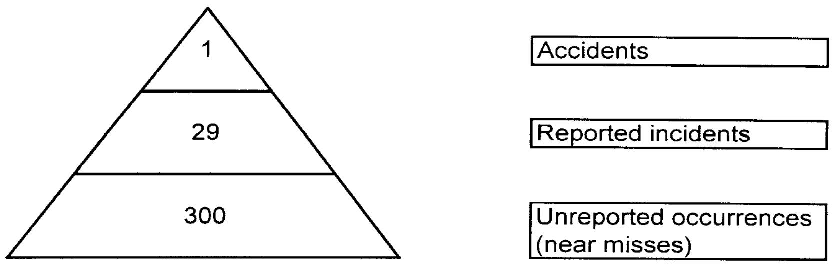

Figure 1: Heinrich Pyramid [19]

3.5 Helideck Operability

From a review of the available incident reports and causes identified, it is concluded that the operability of offshore helidecks has been consistently overlooked, if not ignored, during the design process. The IVLL with its many references to non-compliances and operating restrictions is further evidence that helideck operability has not featured very highly during the installation/helideck design phase.

The situation has apparently not improved with the passage of time, and applies equally to new and old installations. Therefore, a primary goal arising from this research project should be to improve the operability of offshore helidecks. This can be achieved at the design stage by a positive intent to meet the following objectives:

- Minimising adverse environments on and around helidecks where possible.
- Providing flight crews with much better information about the environment on and around a helideck.

Operability, in this case, is defined as a measure of the operational quality of the helideck design when seen from the pilot's and Helicopter Landing Officer's (HLO) viewpoint.

To seek solutions to avoid helideck operability problems in the future, we should ask why helideck operability has been overlooked in the past. The following observations may provide some answers:–

(i) For the most part, helideck designers have always followed tradition and practice and, as a result, have focused on minimum specification and costs unless specifically instructed to do otherwise by the installation operator.

(ii) Helideck designers do not generally have sufficient knowledge of offshore helicopter flight operations and rarely understand the essential needs of a helicopter pilot when landing on and taking-off from offshore installations.

(iii) The designer rarely receives operational feedback about his helideck design from the helicopter operator. This invariably means that he does not find out about operational problems, so the same mistakes are made again on subsequent projects.

(iv) The designer uses CAP 437 as an exclusive design guide. However, it is neither written nor published as a design guide. It primarily exists for the Air Operator Certificate Holder (AOC) and gives the minimum standards the AOC Holder should accept for landing site approval. Simply achieving CAP 437 design compliance does not ensure good helideck operability.

(v) A detailed helideck and facilities design guide, that addresses all aspects of design and operability is not available for designers at present. Such a document would require a completely different approach from that employed in CAP 437. CAP 437 is not, therefore, considered the appropriate vehicle for dealing with both requirements.

(vi) The origins and qualification of CAP 437 Ch. 3.3 performance criteria are not documented (the 2°C temperature criterion is believed to derive from the usual resolution of helicopter flight manual WAT charts). These performance criteria need to be evaluated and re-qualified.

(vii) Helideck aerodynamic and thermal performance simulations generally quantify individual effects, not real life combinations. Simulations are currently performed individually. If feasible, combined testing, using typical flight profiles and operating conditions should be undertaken, particularly where specific problems are apparent or have been reported. This may require development of more sophisticated simulation procedures for the future.

(viii) Flight crews (BHAB) have little, if any, confidence in the design and simulation output. This situation is not helped by the apparent lack of design and testing data CAA/BHAB receive for appraisal. The design and simulation information flow needs to be much improved.

(ix) At present, BHAB rely almost entirely on the reports of pilot flight experiences to prepare the IVLL which includes operability deficiencies such as turbulence, exhaust and flare plume problems, etc.

Figure 2 shows the existing relationships between the regulators, helicopter operator/BHAB, installation owner/operator and designer.

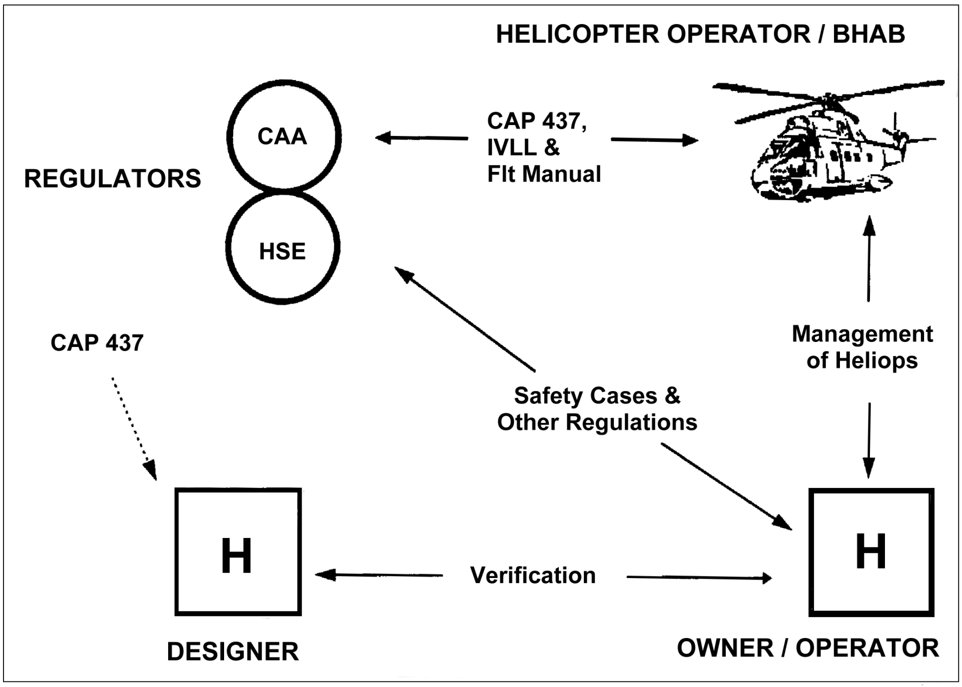

Figure 2: Linkages between regulators, helicopter operators/BHAB, installation owner/operator and designer

The Regulators, Helicopter Operator and Installation Owner/Operator maintain their links for the life of the operation and have regular two way communication and information exchanges. Only the Helideck Designer does not have an established two-way linkage. He is only around for a brief period of time, probably only at the beginning of a project and then moves to the next job.

During the design period there may be a tenuous link between the designer and CAA/BHAB as a result of the verification process. This may not always be the actual helideck designer and/or tester but someone else who is dealing with project verification as a whole. This 'weak' linkage means that feedback to the 'actual' helideck designer is often scant, if it happens at all. Also, on some projects the helideck design task can and often does get split between several disciplines.

It is therefore fairly obvious where the basic problem is rooted. The helideck design task is often fragmented. It is also based on outdated custom and practice which appears to be flawed, and a comprehensive design guide is not available to aid the helideck designer.

4 ENVIRONMENTAL HAZARDS

For a helicopter attempting to land or take-off from an offshore installation, the effects of an environmental disturbance are felt by the pilot as a handling problem or possibly as a loss of power. Such encounters are almost always described by pilots as 'turbulence' but may, in practice, be caused by a number of different effects.

This section identifies the nature of the environmental disturbances which can occur, traces their origins, and describes practical design measures which have been adopted to minimise the risk of pilots encountering a problem.

4.1 Definition of Hazards

4.1.1 *Sources of hazard*

A helicopter flying to an offshore platform is subject to the influence of changes in its external environment as a result of the presence and operation of the platform. The platform causes a change in the wind pattern that would otherwise exist, and its operation leads to modification of the characteristics of the air in places as a result of emissions of hot or cold air and gas mixtures. There also exists the potential for radiant heating from a flare burning vented hydrocarbons and, beyond the flame, a thermal plume from the same source will produce elevated temperatures in some locations.

These influences on the environment through which the aircraft may fly are dealt with individually below. Also in this section the concept of an *environmental hazard zone* is introduced. This is a zone in which environmental hazards may exist and which, from a flying perspective, may best be thought of as a *restricted* flying zone, in some senses analogous to restricted sectors due to physical obstructions.

One further hazard or limitation worthy of mention is that of flying in a cross-wind. Essentially, this is a helicopter flight performance matter and is dealt with in detail elsewhere. It arises here, however, as an environmental hazard due to the fact that the platform does produce restricted flying zones and these may give rise to the need for a flight pattern involving cross-wind flying. This is a matter for consideration in design (location of helideck, Section 4.2) and in planning helicopter operations (Section 4.3).

4.1.2 *Wind flow around offshore installations*

An offshore platform is a major obstruction to the wind and causes the air to flow around, over and under the platform. It not only disturbs the average direction and strength of the wind flow, but also it causes regions of turbulence, areas of gusty re-circulating flow, and regions of acceleration, especially near the major *edges* or *corners* of the platform.

The wind flow around the platform establishes pressure differences between different locations, and these generate secondary weaker flows through and across the platform where paths for air-flow exist.

Thus, the wind which exists over the sea away from the platform, and which is itself turbulent and unsteady and gradually increases in speed with height, is modified by the platform. The nature of the disturbance is familiar to many and has been described in a number of publications e.g. [20].

Anemometers mounted on offshore platforms are intended to measure the undisturbed wind, hence they are usually mounted at a high elevation on a suitable structure, frequently the drilling derrick. However, an anemometer so located is not always in such a position that the wind is undisturbed since there may be distortion of wind speed and/or direction. There is sometimes confusion whether the anemometer reading relayed to the control room has been corrected or not, and whether it has been made equivalent to a wind at 10 m above the sea which is the meteorological standard. For the purposes of providing information to helicopters on the *undisturbed* wind speed and direction in the vicinity of the platform, it would seem logical to provide the information in an agreed standard form, i.e. at 10 m above the sea or, say, at helideck height plus 10–15 m. Giving an indication of speed and direction at the *helideck itself*, is a different matter. This could be provided from information gathered during design studies (e.g. data from wind-tunnel tests) or, at least in theory, from local measurements using hand-held instruments.

In addition to modifying the wind environment over the helideck itself (see 4.1.3), the influence of the platform on the wind extends out from the platform and has the potential to affect helicopter operations. Whilst, to some extent, this influence exists to the side and above the platform, the principal area which is affected is that immediately downwind in the aerodynamic wake of the platform. The wake extends significantly downwind, but the conditions in the wake progressively return to those of the natural undisturbed wind.

From the standpoint of helicopter flight, a boundary could be drawn within which wind speed and direction and levels of turbulence fail to meet criteria for safe operation and, thus, could be defined as a restricted area for flying.

Although the restricted area would rotate with wind direction and shrink and expand with wind speed, it is an area which could nonetheless, be defined relatively simply. This is returned to in Section 4.1.7.

4.1.3 *Wind flow over the helideck*

The wind flow over the helideck is influenced by the broad bulk of the platform itself and by local features of detail.

Thus, if the helideck is on the downwind side of a platform, the wind might be inclined downwards over the helideck as a result of the separated flow from the upwind face of the platform curling down to form the wake. Conversely, when the helideck is close to an upwind face, the probability is that it will be in an air stream inclined upward. Design-phase studies are usually conducted to ensure that such effects are minimised, and the practical steps that can be taken to ease any problems are discussed in Section 4.2.

The turbulence at the helideck will be different from that in the natural wind, owing to the obstructions upwind of the helideck. Common causes of turbulence generation are discrete elements such as lattice structures (drilling derrick), the accumulated wakes of topside elements (tanks, containers, individual modules etc.), and the turbulence formed by the separated flow at the upwind face of the platform.

Conditions will not be identical at every point over the helideck and they will, of course, vary with wind direction and wind speed.

By comparison with the natural wind, the turbulence generated by the platform will have higher frequency fluctuations; the frequency of fluctuations increases as the size of obstructions and their wakes, decrease.

In principle, the detail of the wind conditions over the helideck can be defined to any degree required during the design evaluation stage, but this is only of value if limiting criteria for turbulence and deviation in wind direction for safe helicopter operation are available. Presently, CAP 437 prescribes a limit on the vertical velocity component of 0.9 m/s, but remains silent on turbulence. Evidently, pilots perceive 'turbulence' as the major contributor to pilot workload and a safety hazard [5].

4.1.4 *Hot exhaust plumes*

Power generation on offshore platforms is generally based on gas turbine systems, which produce hot exhaust streams comprised mostly of air. Exhaust temperatures in excess of 400°C are normal. The hot plume is buoyant and is most frequently emitted vertically upwards. The plume is turbulent, rises on leaving the exhaust, dilutes and loses momentum by entrainment of the surrounding air, and is gradually turned by the wind to travel in the local wind direction.

There will always be a wind direction which carries exhausts in the direction of the helideck. The height at which a plume arrives over the helideck will depend on the height of the exhausts, the strength of the wind and the exhaust temperature and momentum. It is important to note, however, that for a vertically upward exhaust outlet, the plume will be carried essentially directly downwind of the stack. This apparently obvious point is significant when considering strategies to avoid flying into potentially hazardous areas (see Section 4.1.7).

CAP 437 requires that notification to operators be given if temperatures in excess of 2°C above ambient are liable to exist over the helideck. This criterion appears to stem from the concept of adjusting payload to take account of ambient temperature changes. The requirement is dictated by the effect of temperature on engine power and the loss of lift from the rotor due to the reduction in air density with increase in temperature. Unfortunately, the plume does not provide anything as simple as a steady rise in temperature above ambient. The temperature in the plume fluctuates and the extent of temperature rise depends on the time interval being considered. Higher temperatures can occur over, say, fractions of a second than can exist, on average, over a number of seconds. The nature of fluctuating temperatures in a turbulent plume is discussed, for example, in [21].

The significance of the period of temperature fluctuations depends upon the response time of helicopter engines. This is dealt with under Section 5.3 but, historically, it has been assumed that raised temperatures need to persist for a number of seconds (say 3) to produce a noticeable change in engine output [4].

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[4] In the Third Edition of CAP 437 (October 1998), released during the course of this project, the averaging period for the 2°C temperature rise is specified as 3 seconds.

4.1.5 *Release of process gas*

There are occasions in the operating life of a platform when gas from the process streams will be vented to atmosphere. Accidental releases may also occur. The aerodynamic behaviour of the released gas will depend upon its density, temperature, venting momentum and location on the platform.

Clearly these are circumstances requiring extreme caution for all platform operations since the release offers the potential for fire or explosion. That said, the extent of flammable/explosive conditions are often defined during the Safety Case process and the principles of entrainment of air and dilution are analogous to that for hot plumes. Away from the immediate area of the source the resulting plume or cloud will be carried in the direction of, and with the speed of, the local wind. The hazard due to the ingestion of hydrocarbon gas mixtures into a helicopter engine is discussed in Section 5.3.

4.1.6 *Flared gas*

Platforms normally have flare towers, comprising tall or long cantilevered structures designed to remove a source of released gas as far away from the platform as is practicable. The flare may also be the location for the venting of unburned gas (see Section 4.1.5), but, specifically, it is designed to burn off excess gas. The Energy Act of 1985 calls for gas conservation so that flaring is essentially for use only in the event of an emergency.

Flares are, of course, highly visible, though the thermal plume beyond the flame is not. The combustion products beyond the flame tip are hot (many hundreds of degrees C), but the process of mixing and cooling is aggressive and the plume dilutes and cools whilst moving downwind much like any other turbulent plume. The hot gas plume from the flare presents a hazard similar to the gas turbine exhausts plume, but it has the advantage of usually being more visible to pilots.

One reason for the flare tip to be well removed from the platform is to avoid radiant heat from the flame affecting personnel, equipment and the helideck. This is considered and dealt with during the platform design phase.

4.1.7 *Environmental hazard zone concept*

As has been discussed above, an offshore platform introduces the following changes to environmental conditions in parts of the air-space surrounding it:

- vertical and cross-wind components of wind velocity
- acceleration and retardation in magnitude of wind vector
- increased intensity and higher frequencies of turbulence
- narrow regions (shear layers) across which environmental conditions change substantially
- rapid fluctuations of, and increase in average temperature
- at times, concentrations of unburned hydrocarbon gases in air

Each of these factors can be hazardous to helicopter operations but, equally, a limit of acceptability can be defined for each. These limits can then be used to define a boundary within which flying should be restricted and outside of which flying is unrestricted.

If an *environmental restriction zone* can be defined, then two zones would be available to regulate flying: the *obstruction-free-zone* and *the environmental-hazard-free-zone* (see Section 4.3).

The environmental-hazard-free-zone can be defined at the platform design stage and could become part of the installation's Safety Case. It should be noted that the zone definition might alter as a result of permanent upgrades to the platform or due to temporary changes, such as the presence of a nearby moored flotel. Maintenance of up-to-date information on the status of environmental-hazard zones would logically be the responsibility of the duty-holder of the installation.

If this concept were adopted, then an additional parameter in the design (new or modification) of platform topsides might well be the minimisation of the environmental-hazard zone. This is discussed further in Section 4.2.

These ideas are in essence very simple, and because the separate hazards form *downwind* of their respective sources, they are not difficult to identify or to avoid (see Section 4.3). It may be argued that, in practice, this is intuitively recognised and caution in flying is suitably exercised. If this is the case, so much the better, since the main requirement in enhancing the safety of helicopter operations, is not to revolutionise, but to regularise, so as to encourage good practice and prevent surprises occurring.

4.2 Platform Design Considerations

4.2.1 *Overall layout and location of helideck*

The helideck is required to be easily accessible from the accommodation and is, thus, sensibly located above the living quarters module. Unless the accommodation is sited on a separate platform, it is located at the opposite end of the platform to the drilling and process equipment, so as to maximise the distance of the living and emergency refuge areas from the main sources of hydrocarbons in the event of fire or explosion. Inevitably, the accommodation and helideck are then in the vicinity of the utilities, generally including the exhausts from the power generation plant.

There is always a wind direction which places the helideck downwind of a particular platform feature which can generate an environmental hazard whether it be exhaust plumes, turbulent wakes, flares or gas releases. A primary requirement is to maintain sufficient separation between the helideck and the sources of environmental disturbance. It is not possible to completely eliminate all influences, so the design is very much a matter of specific detailed consideration and assessment.

To avoid the worst effects of down-flow when the helideck is on the downwind side of the platform, it must be located high on the platform, with further detailed considerations as in the following sections. Many rectangular 'plan-form' platforms have the helideck cantilevered off one corner of the accommodation. From the layout point of view and the ease with which a 210° obstacle-free zone can be created, this is attractive. However, avoidance of the worst wind effects from the platform may be better achieved by placing the helideck more centrally over the accommodation block, cantilevered in just one direction off the edge of the platform. This, at least, places the helideck nearer the edge of the platform wake more consistently for a range of wind directions with potential advantages for reducing the extent of a flight path in disturbed air.

In reality, this consideration is best achieved in the context of specific platform details, together with input on preferred flying strategies. Thus the need to involve flight operations planning at an early stage of design.

With such input it would be possible to evaluate alternatives in terms of estimated *availability or operability* of the helideck in the particular wind climate of the platform's location.

4.2.2 *Helideck and air-gap*

For winds onto the platform, such that the helideck is above a windward face, it is important to remove the helideck from the upward 'cliff-edge' flow that the bulk of the accommodation block produces. This is best achieved by allowing an airflow beneath the helideck and usually requires the helideck to be cantilevered out, by say half its diameter and raised clear of the top of the module by something in the region of 3 m. Needless to say, the air-gap must remain clear and not be converted into a convenient storage location for bulky items.

With such a configuration the local airflow is *straightened* and made to flow relatively horizontally over the deck. The further the helideck is away from the windward face of the platform, the less the influence of this feature will be, so it principally contributes to a good air-flow for probably less than half the wind directions.

4.2.3 *Gas turbine exhaust outlets*

Minimisation of the impact of hot exhausts (see Section 4.1.4) has generally been regarded as keeping the helideck itself free of excess temperature, at least to a reasonable height (say greater than 20 m above deck level). Ideally, in conjunction with flight operations planning, approach and take-off flight paths should also be considered.

Exhausts on offshore platforms have been directed upwards, horizontally and downwards. As a general principle, vertically upward exhausts are to be preferred. These produce predictable, undistorted plumes, which can be avoided by helicopters by keeping clear of downwind locations at the exhaust height and above, and they can usually be elevated sufficiently to keep the immediate helideck area clear of excess temperatures for all wind speed and direction combinations.

Downward facing exhausts are, by contrast, difficult to control, especially in light winds when they suffer less dilution and, being buoyant, rise to helideck height and above. Downward plumes are carried by the relatively complicated airflow beneath and around the platform and their precise location is difficult to judge. There have also been experiences of adverse effects of heating of the platform structure.

Plumes ejected horizontally outward from the platform can be blown back on to the platform for some wind directions and, even when swept away from the platform, they do so from an indeterminate (varying with wind speed and exhaust rate) position out-board of the platform. Thus the visual judgement of where the plume is likely to be becomes difficult and also, significantly, the *footprint* (plan view) of the total environmental impact of the platform (disturbed flow plus elevated temperature) is, undesirably, enlarged in size by this configuration.

It should be noted that the foregoing remarks relate to installations which are fixed in position relative to the wind. For floating units which weather-vane, the relationship between exhausts, helideck and flight path, will be more constant and specific advantage can be taken of dealing with an effective *narrow band* of wind direction.

4.2.4 *Flare location*

The flare tower (vertical structure) or flare boom (inclined lattice structure) is designed to remove the flare tip a sufficient distance from the platform to ensure that the radiated heat from the flame is not a problem on the platform itself. The flare boom is located at the process end of the platform and the initial design requirement is to keep temperatures at acceptable levels in the associated working areas. The helideck is, necessarily, considerably more distant from the flare and special considerations for radiant heat should not be required.

As far as the hot plume emitted by the flame is concerned, it will generally be at sufficient elevation to be well clear of the helideck. During approach and take-off, if the flare is alight the plume alignment will be downwind of the tip and generally higher. The plume may thus be avoidable by exercising precautions in flight, supported by information on flare plume characteristics derived at the design assessment stage.

From the standpoint of design *per-se* relatively little can be done to make the flare more helicopter friendly.

4.2.5 *Gas blow-down systems*

In the event of process upset, there may be an operational requirement to discharge hydrocarbons to the atmosphere. Generally it will be preferable to burn the released gas in a controlled fashion and so the blow-down system is led to the flare boom.

Significant gas releases are fortunately rare events, with just 16 major releases reported in 1996/97 under the Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995 [22]. If the discharged gases are released unburned then a significant hazard of mixtures which are potentially flammable can exist. From the standpoint of helicopter operations, this is a situation which can only be avoided by information and communication with the platform. Such procedures should logically form part of the platform operational Safety Case.

4.3 **Helicopter Operational Considerations**

4.3.1 *Environmental hazard studies*

Helidecks designed to satisfy the recommended minimum standards specified in CAP 437 may, none the less, result in a hazard to subsequent helicopter operations due to circumstances not specifically included within the design remit. To date, environmental studies conducted in support of design safety cases have focused very much on conditions immediately above the helideck. There are probably three principal reasons for this situation:–

(i) The region immediately above the helideck represents a well defined spatial location within which a helicopter is bound to be required to operate regardless of the flight path selected by the pilot for either a landing approach or a climb away after take-off.

(ii) This is almost certainly the closest point on the overall flight path to the source of any environmental disturbance. Hence the effects of the disturbance are likely to be at their most severe at this point in the flight path.

(iii) Whilst hovering immediately above the helideck, the helicopter is judged to be at its most vulnerable to an environmental hazard.

There are, however, sound reasons for extending the scope of environmental hazard studies to include a larger field covering both the approach and take-off flight paths. This topic has largely been neglected to date due partly to the fact that the most critical conditions are judged to occur immediately above the helideck, and partly to the fact that information on likely flight path routes is not generally available at the platform design stage. However, it is also apparent that information from environmental hazard studies currently conducted for design purposes does not readily find its way into the helicopter operations domain.

It is proposed that the issue of flight path planning or *helideck operability* is brought forward and considered as an integral part of future environmental hazard studies. This will necessarily involve full disclosure by the rig operator of details of any units in the immediate vicinity, either permanent or temporary, which may have the potential for creating an environmental hazard for helicopters.

4.3.2 *Approach and take-off strategies*

If a flight-path plan is drawn up in parallel with the development of the design for a new installation it should then be possible, often by a simple process of inspection, to determine whether there are circumstances in which a helicopter could encounter an environmental hazard during its approach to, or take-off from, the installation. Once the appropriate circumstances have been identified, it should be possible to specify the relevant conditions for more detailed investigation as part of any wind-flow studies commissioned in support of the safety case.

As an example of what is proposed, a simple case study has been undertaken to demonstrate some of the possible outcomes. It has been assumed that operations are to be made to a helideck which satisfies the basic obstacle-free requirements specified in CAP 437. An idealised flight operations plan has then been devised based on two basic requirements. These are:–

(i) Approach and take-off should ideally involve the helicopter maintaining an into-wind heading at all points along the flight path.

(ii) Approach flight paths should provide for an overshoot which does not encroach on the restricted zone in the event that the landing approach is aborted.

The result of this exercise is presented in Figures 3[5] (a) and (b). Two types of approach and take-off manoeuvre are required to satisfy the requirements specified above. They are:–

[5] It should be noted that Figures 3 and 4 illustrate principles only, and should not be considered to be representative of actual flight profiles.

A *direct* flight path involving a flight directly to or from a hover point immediately above the landing spot.

An *indirect* flight path involving a flight directly to a hover point alongside the helideck. An additional step in the form of a sideways transition facing into-wind, is needed to bring the helicopter to a second hover point immediately above the landing spot.

4.3.3 *Interaction with environmental disturbance*

If the helideck is now considered to be part of a typical fixed installation which includes, say, a gas turbine exhaust source, then it is possible to superimpose the track of the environmental disturbance on the specified flight path for a given wind direction.

This process is illustrated in Figures 3(a) and (b) where it is immediately clear that, for the proposed flight-path plan, an environmental hazard exists only in the immediate vicinity of the helideck. The reason for this simple but nonetheless important conclusion is that the proposed operations scenario has resulted in the track of the helicopter remaining parallel to and displaced from the track of the environmental disturbance. It is only during the sideways transition that the separation between the tracks can reduce to zero. In the four cases involving indirect landing and take-off tracks illustrated in Figures 3(a) and (b), only one, that for the wind direction range of 090° to 165°, involves the flight path crossing the track of the exhaust plume. In such a case, it may be appropriate to impose a restriction on flying operations if the recommendation made under Section 10.1(v) is implemented.

The situations illustrated in Figure 4[6] show two possible circumstances where the helicopter flight path and the track of a gas turbine exhaust plume could intersect. They involve:

- Flight paths that are not directly into-wind. This results in non-parallel tracks which can therefore intersect at a point other than immediately over the helideck.

- Gas turbine outlets that exhaust other than vertically. This produces a plume whose track will be determined both by the direction and strength of the wind, such that the plume path can intersect the track of the helicopter at a point remote from the helideck.

Such cases need to be identified and appropriate restrictions applied.

It is also relevant to speculate on the effects of a second platform in close proximity to the installation to which the helicopter is flying. It would appear that, in general, the same overall conclusion will apply if the flight path plan is based on the requirements specified under paragraph 4.3.2. However, it would be unwise to generalise in this respect and a review of each case will need to be undertaken.

[6] It should be noted that Figures 3 and 4 illustrate principles, and should not be considered to be representative of actual flight profiles.

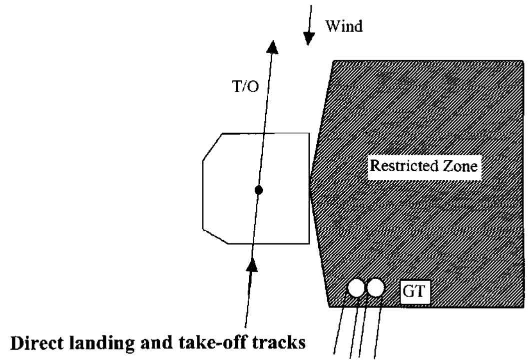
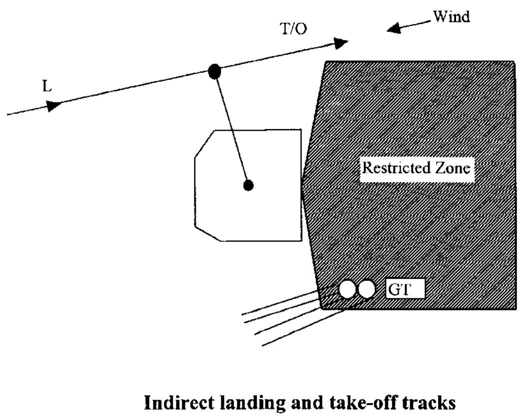
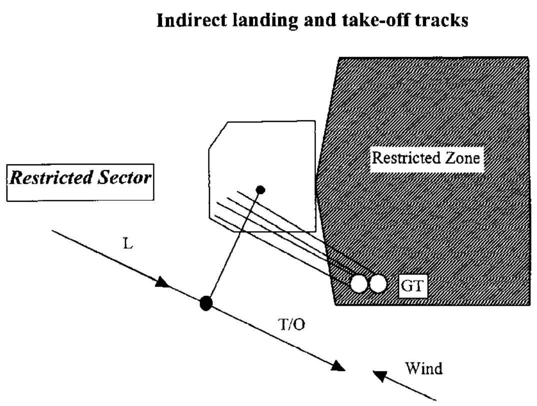
Wind direction range	Landing and take-off tracks
345° - 015°	
015° - 090°	
090° - 165°	

Figure 3(a): Optimised landing and take-off strategies avoiding gas turbine plume (see Footnote 5)

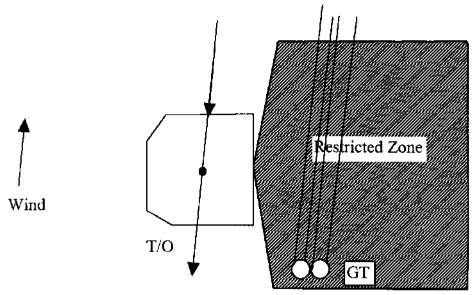
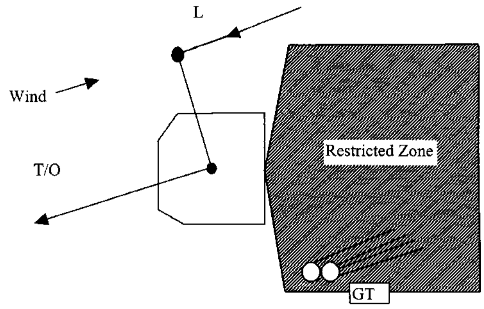
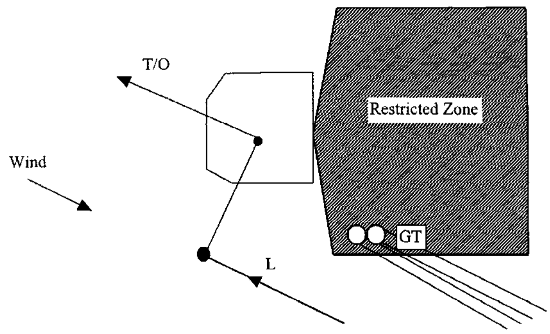
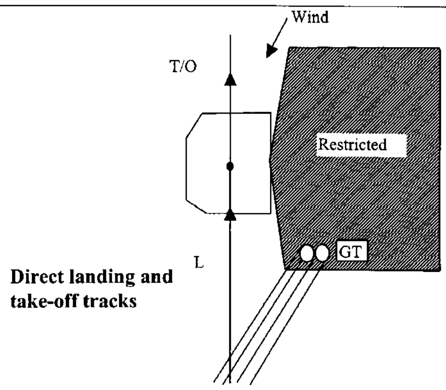
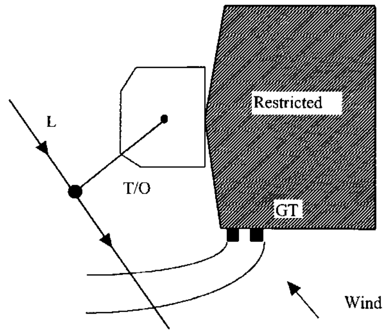
Wind direction range	Landing and take-off tracks
165°- 195°	 **Direct landing and take-off tracks**
195°- 270°	 **Indirect landing with direct take-off track**
270°- 345°	**Indirect landing with direct take-off track** 

Figure 3(b): Optimised landing and take-off strategies avoiding gas turbine plume (see Footnote 5)

<table>
<tr><th>Hazard case</th><th>Conditions for possible intercept with plume path</th></tr>
<tr><td>Landing approach oblique to the wind</td><td>
</td></tr>
<tr><td>Gas turbines exhausting horizontally</td><td>

Indirect landing and take-off tracks</td></tr>
</table>

Figure 4: Landing and take-off strategies involving a risk of contact with a gas turbine exhaust plume (see Footnote 6)

5 IMPLICATIONS FOR HELICOPTER PERFORMANCE AND HANDLING

A key issue linking the nature of the environmental disturbances described in Section 4 with the problems encountered by pilots (Section 3) is the response of the helicopter itself to sudden changes in environmental conditions. In this section, therefore, the emphasis is on the helicopter as a machine and its responses to different forms of environmental disturbance.

This is an important feature of the study since it 'closes the loop' by linking the behaviour of the helicopter, as experienced by the pilot, with the nature of the environmental disturbance, the origins of which can readily be traced back to the basic design of the installation.

5.1 Aircraft Response to Atmospheric Turbulence and Temperature

5.1.1 *Performance and handling qualities*

Helicopters operating to and from helidecks on offshore platforms are exposed to the invisible effects of local atmospheric disturbances in the form of distorted and concentrated airwakes caused by structure induced turbulence and down-draughting, and hot gas plumes from gas turbine exhausts and flares. The invisible nature of these disturbances makes it difficult for the pilot to anticipate the required control action to negate their effects. The importance of the effects of the disturbed flow around helidecks has been highlighted in two previous studies conducted for CAA [5] [12]. Key questions arising from this simplistic perspective are what strength of disturbance is tolerable in terms of the effect on aircraft performance and handling qualities, and how do aircraft design parameters influence these effects.

5.1.2 *The nature of disturbances*

Close to the ground and obstacles, atmospheric disturbances can be generated by four different mechanisms:

- Unsteadiness caused by turbulence developing in the velocity gradients in the atmospheric boundary layer, and the convective motions of the atmosphere due to natural temperature variations which can often take the form of gusts.
- The evolution in time of vorticity shed from structures. This mechanism gives rise to strong spatially correlated unsteadiness.
- Instability of separated flow characterised by moving separation or attachment lines.
- Spatial variation of the steady airwake which, whilst stationary, will give rise to disturbed motion as the helicopter flies through it.

Clearly, while it is important to understand the different mechanisms when modelling atmospheric motion or designing ameliorating devices, the pilot ultimately experiences and will react to the combined effect of these disturbances. The combined effect can be understood in terms of the frequency range of the disturbances and it is convenient to distinguish three regions:

- Disturbances with a frequency content above about 10 rad/s, as typified by turbulence, will vibrate the helicopter giving a more uncomfortable ride and making it more difficult for the pilot to read instruments. Such disturbances however will not have much impact on the flight trajectory of the aircraft.

- In the broad range between 1 and 10 rad/s, as featured in an unsteady airwake for example, disturbances can rotate and push the aircraft around to an extent that the pilot will normally adopt a closed loop attitude-stabilisation control strategy to minimise the effects of the disturbances, and to hold a flight path or position.
- Low frequency disturbances, below about 1 rad/s (as, for example, experienced by a helicopter moving slowly through a spatially varying airwake), can result in significant flight path excursions unless counteracted by the pilot.

As an illustration of the powerful nature of airwake effects, Figures 5 and 6 show results from an empirical analysis of the steady component of the air wake, at rotor height, at the aft end of a Type 23 Frigate where the wind over deck is 30 knots from 30° starboard. Figure 5 shows the horizontal component flow lines while Figure 6 shows contours of the vertical component, with a negative value representing a downdraught. The cross on the deck gives the location of the landing spot, while the hanger face is at the top of the plot. The helicopter approaches from the port side, side-steps over the deck through the area of strong downdraught and station keeps over the landing spot until a suitable quiescent period when it is safe to touch down and engage the deck lock. The region of strong vertical flow gradient on the port edge of the deck represents the greatest hazard to safe helicopter operations in this case. As the helicopter traverses through this region the rotor will initially experience a downdraught peaking at 6 m/s, followed by an upwash peaking at 4 m/s.

5.1.3 *Response to horizontal gusts*

At low speed, the initial translational acceleration response of a helicopter is relatively insensitive to horizontal gusts. Typical values of surge and sway acceleration responses to a sharp edged gust are 0.002 and 0.005 g/m/s respectively, values which do not seem to vary between helicopter types (for conventional single main rotor and tail rotor layouts). The heave response to a horizontal gust will depend on a number of rotor design parameters, including blade loading and rotor speed, but is also small with maximum values around 0.0025 g/m/s. Angular accelerations can vary significantly with helicopter size and rotor configuration and are generally much higher than translational accelerations. Roll (pitch) accelerations as high as 23 $deg/s^2/m/s$ can occur on small hingeless rotor types, (e.g. Bo105) reducing to one quarter of these values with medium sized helicopters featuring articulated rotors (e.g. Puma). Because the rotor damping moment varies in the same manner with rotor type as the disturbance moment, the resulting attitude change is much the same, although the hingeless rotor helicopter will achieve steady state more rapidly. A medium sized articulated rotor helicopter would be expected to be rolled over about 20° in 3 seconds in response to a 5 m/s side gust. In the vicinity of a helideck, the potential for large and abrupt changes in horizontal velocity depends on the design of the surrounding structures; shear layers springing from sharp vertical edges of bluff structures can present an effective horizontal gust to a transitioning helicopter. Turbulent air motions containing gusts with horizontal components up to several m/s are possible with mean winds of 10 m/s and higher. The spatial distribution of such gusts result in the aircraft being subject to penetration effects on the rotor, which may lead to increased initial acceleration transients.

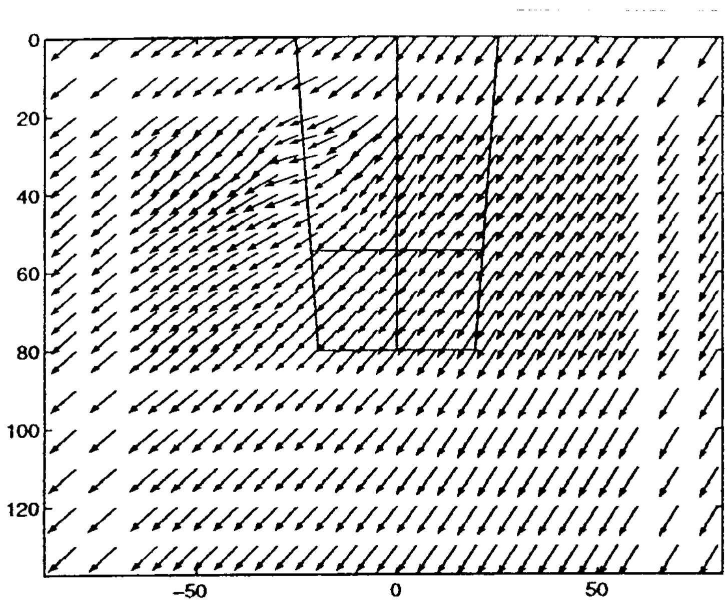


Figure 5: Computed horizontal flow lines over the flight deck of a Type 23 frigate

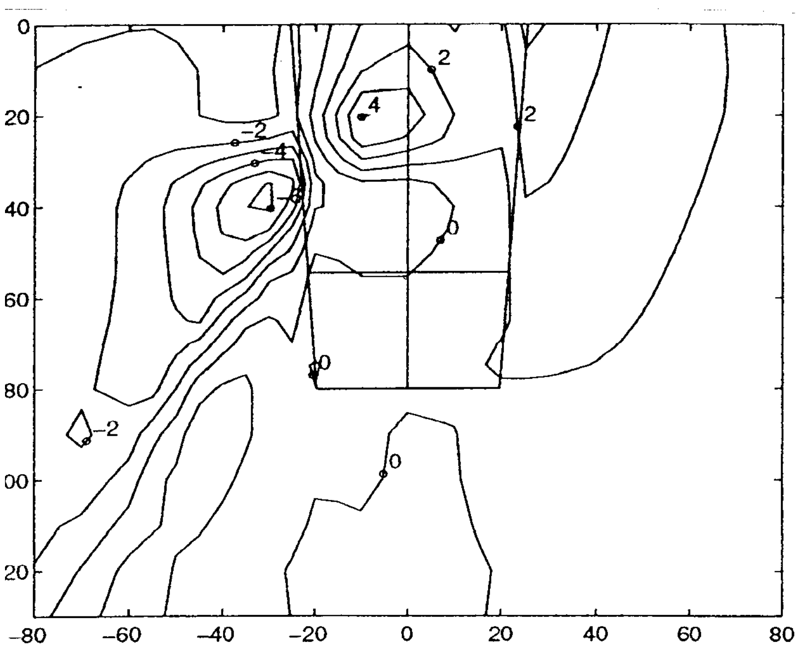


Figure 6: Computed vertical flow lines over the flight deck of a Type 23 frigate

Yawing acceleration in response to horizontal gusts will also vary with type but a value of 1.5deg/s^2/m/s is typical. While the immediate effects on yaw motion appear smaller, the overall piloting problems caused by disturbed motion in yaw can be more significant. For military operations to ships for example, the yaw axis and associated pedal margins usually dominate the ship-helicopter operating limits (SHOLs). The potential loss of yaw effectiveness at so-called critical azimuths can result in the yaw axis becoming particularly difficult to control because of multiple aerodynamic interactions. More generally, yaw control can be very 'loose' because of deficiencies in natural stiffness and damping. The importance of good yaw response characteristics in the presence of gusts is reflected in requirements being set for this behaviour in the military flying qualities standard ADS-33 [23]. The criteria is set in terms of the yaw rate after 3 seconds, following a sharp edged gust as shown in Table 1.

Mission Task Element (MTE)	r_{pk}/vg (deg/s^2/m/s)	
	Level 1	Level 2
Target Acquisition and Tracking	0.66	2.95
General MTEs	0.98	3.3

Table 1: Maximum Allowable Yaw Rate Response to Lateral Gusts

The acceptability of rotorcraft flying qualities for mission tasks is quantified in terms of three levels [24]:

(i) Level 1 corresponds to good flying qualities that enable the pilot to achieve a desired level of performance, well within the margins of error for the mission task, and at a low workload, corresponding to minimal control compensation.

(ii) Level 2 corresponds to flying qualities with tolerable deficiencies that enable the pilot to achieve an adequate performance standard, just within the margins of mission task error, but possibly requiring extensive pilot compensation, hence high workload.

(iii) Level 3 corresponds to flying qualities with major deficiencies that intrude significantly on the pilot's ability to achieve even the adequate performance standard in a mission task, with maximum tolerable compensation. Level 3 is not appropriate for operations to offshore installations.

Without yaw axis control augmentation, helicopters would naturally fall well outside the Level 2 limits. The military requirements are driven by the need to reduce pilot workload in hovering tasks, to ensure that spatial orientation is not compromised when the pilot's attention is divided, and to ensure a steady weapon platform. Read across to civil operations near the helideck of an offshore platform is particularly relevant in degraded visual conditions.

A pilot flying a helicopter into a region with horizontal disturbances can therefore expect the aircraft to experience the largest perturbations in the angular, particularly roll, motions. In response to moderate disturbances, attitude and heading changes of 10–20° can build up in a short time unless checked by the pilot. A pilot's workload will increase as constant attention is required to maintain attitude and to force the aircraft to maintain the desired flight path or position. Good visual cues are vital to safety in such situations. Night, and other degraded visual conditions, bring special problems for the pilot who has to fly 'eyes out' with limited attitude and velocity cues. In such situations, the most useful form of control augmentation will relieve the pilot from the attitude stabilisation and heading hold tasks. However, strong stabilisation functions can also deprive the pilot of agility which may be necessary in emergency situations.

5.1.4 *Response to vertical gusts*

At low speed, the response of a helicopter to vertical gusts is dominated by heave. Acceleration response values between 0.02 and 0.04 g/m/s are typical depending on rotor design and operating condition. This initial 'bump' due to a sharp edged gust will be followed by an exponential type growth in velocity (decay in acceleration) to a steady state rate of climb or descent. Time constants to 63% of steady state climb/descent vary between 2 and 5 seconds depending on rotor design. Simple momentum theory, where the rotor is represented as an actuator disc, predicts that the final steady state rate of climb/descent varies only with thrust/control margin and rotor tip speed. Heave axis response characteristics have a significant impact on a helicopter's agility in low speed manoeuvring. According to the handling qualities standard ADS-33 [23], the key response parameters can be derived from the response to a step command in collective pitch from a hover. The response should have a qualitative first order shape and, for Level 1 handling qualities, the time constant to settle to 63% of the steady state rate of climb should be less than 5 seconds and the rate of climb within 1.5 seconds should be greater than 0.81 m/s, the latter indirectly providing a measure of the required hover thrust/power margin. For Level 2 handling qualities, there are no minimum requirements on time constant but the rate of climb should be greater than 0.28 m/s in 1.5s. For an aircraft with a rate response time constant of 3s, simple momentum theory predicts that the Level 1 standard will be met with a hover thrust margin of about 6% and a maximum hover climb rate of 1.8 m/s.

Annex 5 provides an analysis of the helicopter response to a vertical gust and consequent pilot recovery action through the application of collective pitch. A number of simplifying assumptions are also discussed. Based on the above discussion, and the results derived in Annex 5, the following observations are made:–

(i) CAP 437 [9] proposes a maximum vertical component over a helideck of 0.9 m/s. Simple theory suggests that, in the absence of ground effect, a thrust margin of at least 3% would be required to overcome the effects of this magnitude of gust and maintain a hover over the deck in zero wind. However, it should be noted that it is unlikely that with current helideck designs a helicopter could ever experience a 0.9m/s downdraught in the absence of the beneficial effect on thrust margin of a significant horizontal wind component.

(ii) For an aircraft that just meets the ADS-33 Level 1 performance criteria (i.e. 6% thrust margin, $hdot_{max}$ = 1.8 m/s), and with a heave time constant of 3 seconds, Figure A2 of Annex 5 shows that with a pilot reaction time of 1.5 seconds the aircraft will sink about 0.5 m following application of maximum collective before settling out. The same helicopter hovering at about 2 m skid/wheel height above the deck could withstand a gust of about 0.95 times the maximum rate of climb, i.e. about 1.7 m/s, with a 1.5 second pilot reaction time.

(iii) With the minimum Level 1 stability margin (aircraft time constant of 5 seconds), the same aircraft and pilot hovering at 2 m could successfully recover from a gust of 1.3 m/s before hitting the helideck.

(iv) The nature of pilot reaction time needs to be better understood. In good visual conditions with the pilot giving full attention to the flying task, the reaction time could well be less than 0.5 seconds. In degraded visual environments (DVE), as the helicopter flies over the deck, the pilot's ability to perceive vertical velocity changes will also be degraded as spatial awareness reduces. Also, if the pilot is required to operate with divided attention (DAO) while hovering over the deck, he may not notice velocity changes for some time. In both DVE and DAO, the pilot reaction time could be significantly longer than 0.5 seconds. A value of

1.5 seconds is used for the above analysis to align with the typical value used for analysing an aircraft's susceptibility to automatic control system failures. Def Stan 00970 [25] suggests 1.5 seconds as the required 'pilot response time' for attentive hands-on flight.

(v) The heave response time constant is a function of several design parameters as indicated by Equation A2 in Annex 5 (inverse of damping). Increasing rotor speed (actually tip speed) or reducing the blade loading decreases the time constant. The time constant is also inversely proportional to atmospheric density, a point covered in the next section.

(vi) The analysis in Annex 5 assumes that the helicopter installed performance is sufficient to recover from the effects of a vertical gust. From Figure 5 it can be seen that the downdraught strengths close to a ship's deck can be several times larger than the values discussed above and the gradients significant. It has been shown that aircraft with hover thrust margins of about 3% can withstand the effects of the 0.9 m/s vertical gust. Linear analysis predicts the requirement for a 14% thrust margin to withstand the effects of a 4 m/s vertical downdraught. Alternatively, irrespective of the thrust margin, an aircraft would hit the deck with a velocity of 2 m/s from a hover height of 2 m in just 2 seconds without pilot intervention, after flying into such a gust. The touch down velocity raises the issue of undercarriage strength and allowable rates of descent at touchdown. Most helicopters land one wheel at a time because of the non-zero hover pitch and roll attitudes. Undercarriage limits of about 3 m/s are typical of military aircraft, although this can decrease significantly for a heavy landing on one wheel (<2 m/s).

(vii) The need for a short heave time constant in addition to sufficient thrust margin is reflected in the 2-parameter requirements of the military ADS-33 standard [23]. However, research conducted by DERA on handling requirements for maritime helicopters [26] [27] has shown that the deck landing task can be considerably more demanding for the heave axis than the battlefield bob-up, which served as the design mission task element for ADS-33.

(viii) When is a shear layer a gust? In the analysis conducted it has been assumed that the rotor is instantaneously immersed in the gust. In practice the rotor will gradually penetrate the gust, or vice versa, and the overall effect on rotor thrust will be reduced. It should be noted that the impact of penetration is likely to be stronger on rotor moments and therefore attitude changes; this has not been explored in the present study. The severity of the heave response is strongly dependent on the velocity gradients. Figure 5 shows that the gradients behind the bluff shape of the aircraft hanger on a ship can be very strong and certainly give rise to piloting problems. It has also been shown that the ability to safely operate in downdraughts depends critically on the hover/thrust margin. Irrespective of the velocity gradients, if a helicopter does not have the available thrust margin to hover in, say, a 4 m/s downdraught then the pilot will not be able to avoid being pushed onto the deck. But it has also been shown that, regardless of the thrust margin, with such a strong gust, the pilot needs to take counter action fairly quickly to avoid a dangerous situation. There is a relationship between the gust strength, spatial velocity gradient, aircraft velocity, pilot reaction time and height lost during recovery. No analysis of this relationship has been undertaken in the present study, but it is likely to reveal acceptable gradients to give equivalent recovery profiles to abrupt gusts.

5.1.5 *Rotor droop, power settling and vortex ring condition*

A discussion on helicopter behaviour in the presence of downdraughts would not be complete without reference to a number of handling qualities deficiencies peculiar to this operational region. First, the rotor speed response to power changes and changes in flow through the rotor depends critically on the time constants associated with the governing and fuel flow systems. These can vary from fractions of a second to several seconds in different designs. In the analysis conducted in this report instantaneous rotor response has been assumed, but for the helicopter designs with slow governing systems this assumption is invalid. The delays in the rotor thrust generation introduced by slow governors need to be added to the pilot reaction time and this is likely to make some designs more susceptible to performance and handling problems than others. This is such an important parameter for heave handling qualities that further work is warranted to examine typical variations with in-service aircraft, whether there is any correlation with problems experienced and how airworthiness requirements might be defined.

The second and third topics are closely related yet quite distinct. Reference [28] discusses both power settling and vortex ring. Power settling can be experienced by helicopters when flying at steep descent angles at low speed but well away from hover. In this context, any problems associated with power settling are more likely to be experienced during steep approaches rather than over the helideck itself. At very steep descent angles (>60°) an increase in power can cause the aircraft to eventually sink rather than climb, due to the increased inflow through the rotor increasing the induced power required in a very non-linear fashion (see [28] p204). High descent rates can build up during, for example, downwind turns if the pilot does not attend to power management correctly. Flaring to reduce the rate of descent can exacerbate the situation further. A pilot is perhaps most susceptible to making errors of judgement associated with power management during degraded visual conditions and poor handling qualities in these conditions can be fairly unforgiving.

It is likely that routine monitoring of FDR records (see sections 2.4 and 3.2.2) would help to identify the variation in handling qualities due to rotor droop and power settling.

The third topic is the vortex ring condition which occurs at very low airspeed (< 10kn) and moderate rates of descent (between 500 ft/min (2.5 m/s) and 1000 ft/min (5 m/s)). In vortex ring, the flow through the rotor develops rapidly into a toroidal type of re-circulation, stalling the outboard stations and reducing the incidence of inboard stations. A helicopter's rate of descent can build up to 10 – 15 m/s within seconds of entering vortex ring. When manoeuvring at low speed over a helideck, a helicopter is most susceptible to vortex ring from updraughts which effectively puts the rotor into descent relative to the air. It is not known whether incipient vortex ring has ever been experienced over a helideck; it is doubtful whether the flow conditions could develop as they do in free air so close to the deck itself but sometimes the updraughts are experienced before the helicopter crosses over the deck. Scrutiny of incident databases for evidence of any such effects may be informative.

5.1.6 *Temperature/density changes*

Operations to offshore platforms can be compromised due to the adverse effects of temperature gradients due to the presence of hot plumes. In such conditions, one concern is the ability of the rotor to generate sufficient lift, or the engines to generate sufficient power to remain in safe flight. In hover and low speed flight, more than 70% of the power required comes from the need to overcome the induced drag of the rotor – the power required to lift the helicopter and impart downward momentum to the air. Atmospheric temperature changes in themselves, while important when considering engine performance, do not significantly effect rotor performance; it is the ensuing reduction in air density accompanying an increase in temperature that influences the lifting capability of the rotor through an increase in induced drag. Rotor blade sections have to work at higher incidence to generate the same lift resulting in an increase in rotor downwash and hence the need for more power. In contrast, the profile drag/power required reduces as the density decreases. The induced power Pi can be related to the rotor thrust T through simple momentum theory [28] by the expression;

$$Pi = T^{3/2}/(2\rho A)^{1/2}$$

where A is the rotor disc area and ρ is the air density. From this relationship the extent of power change required when the density changes at constant rotor thrust can be calculated. Hence the expression;

$$\delta Pi / Pi = -(1/2)\ (\delta\rho/\rho)$$

A 10% change in air density (equivalent ISA change from sea level to approximately 3500 ft) requires a 5% change in induced power, or approximately 3.5% change in total power (assuming the induced power is 70% of total power in hover and the change in profile power is negligible). In addition to reducing the thrust margin (3.5% power margin corresponds roughly to about 2.5% thrust margin), a decrease in atmospheric density also increases the heave response time constant, so there is a degradation in both handling and performance. The relationship of density with air temperature is more complicated and depends, among other things, on the type of heating. The overall effect on the helicopter depends on further factors including the movement of the airflow. In this study this aspect has not been addressed.

A 10% reduction in air density would, for example, occur if there were a 30°C increase in temperature on top of an ambient temperature in the range 10 – 20°C at constant pressure. As stated above, this change in density corresponds to roughly a 2.5% reduction in thrust margin. The 2°C temperature rise threshold in CAP 437 [9] therefore equates to approximately a 0.17% thrust margin due to the loss of lift from the rotor.

5.2 Mitigating technologies and requirements development

5.2.1 *Control margins and operational envelopes*

The performance and handling limitations associated with environmental hazards at offshore helidecks can be countered in a number of ways. Restricting the operational envelope is a safe approach, provided sufficient knowledge on the conditions at the helideck are available. More positively, there are a number of developments in flight systems that offer the opportunity for opening up the operational envelope while increasing safety.

As described in earlier sections, any adverse environmental effects close to the helideck can result in the helicopter being exposed to disturbances that can result in rapidly changing control requirements which, in worst conditions, can exceed the available margins. Two aspects contribute to the risk of serious consequences following inadvertent entry into strong disturbances. First, the pilot has little or no awareness of the aircraft's aerodynamic flight path from his instruments; the control positions to trim provide the primary cues, but by the time the pilot achieves these, the adverse conditions have been entered. Second, when flying close to the helideck, the pilot's attention is drawn to inertial flight relative to the surrounding structure, further reducing aerodynamic situational awareness. In general terms, any flight system designed as an aid to the pilot in such situations can either provide assistance in avoiding entry, or assistance in recovery following entry. Such systems can operate in three modes:–

(i) provide warnings to the pilot,

(ii) provide guidance to the pilot through a director cue on how to manoeuvre away from, or out of, the adverse region,

(iii) provide direct intervention by the control system providing stability and guidance augmentation or, ultimately, automated recovery.

Combinations of these modes are also feasible so that partial automation, for example, could form a part of a manual director system.

5.2.2 *Cueing systems*

Warning and director cueing systems operate by demanding attention through audio, visual or tactile senses. Audio warnings can be relatively simple in concept and straightforward to implement. Helicopter pilots rely on a wide range of audio cues to warn them of system failures and aerodynamic limits (e.g. blade slap indicating increasing rotor loads). Such systems can be very effective at alerting the pilot, but can also go unnoticed in conditions of high workload or when the audio environment is cluttered (e.g. with other warnings and communications). The problem is compounded by the need to select an audio signal that is distinct from others. It seems intuitive that, to be effective on its own, a warning system should cue the pilot to take particular action without further interpretation. The use of 3D audio has the potential for alerting and guiding the pilot. There is some evidence that including information within an audio cue that the pilot has to interpret might conflict with the visual flight task unless the two demands are synergistic.

Pilots also depend on visual cueing/warnings presented both head-down on the instrument panels and on helmet mounted displays, although the latter are not yet seen in civil operations. Warnings can take the form of flashing symbols/attention getters but, as with audio cues, in high workload situations such warnings can easily go unnoticed. A visual director system has obvious attractions, particularly when presented in a head-up format which is likely to be an essential requirement for recoveries to helidecks. The ergonomics of such displays is critical to their effectiveness, however. For example, displays which require the pilot to fixate on symbology that does not conform with the outside world can result in a reduction in all-round situational awareness, which will be very important during the final phases of the approach to a helideck. A director-based system must also be unambiguous in its guidance to the pilot on the required control strategy. The requirements for conformity and clarity translate into display features that are intuitive to the pilot. For such a display to be useful in helping the pilot avoid areas of strong velocity gradients, some information on the status of the airflow over the helideck must be available on the display.

A tactile cueing system should also be intuitive. For example, if applied through the lever, stick or pedals, the controls should move in the direction of recovery. Tactile cues can also be applied through the pilot's seat or through the hand grips. Research into heave axis carefree handling systems has demonstrated the potential benefits of tactile cueing to both safety and performance in high workload situations [29].

5.2.3 *Flight control augmentation*

Direct intervention systems operate through the automatic flight control system, their signals being superimposed on stabilisation inputs. The effectiveness of such systems is critically dependent on the actuator authority available to the control system beyond that required for stabilisation. A well designed intervention system will work in harmony with the stabilisation function and provide sufficiently rapid and precise control action to assist the pilot. One of the potential problems with a direct intervention system is that, while the pilot may appreciate assistance from the control system, the nature of this assistance is likely to depend on what the pilot is trying to do; building this 'intelligence' into a control algorithm would be far from straightforward.

More basic forms of intervention system can be designed into the automatic control system to improve the handling qualities through response type augmentation. In a recent study conducted by DERA Bedford for the CAA, significant improvements in safety and performance resulting from attitude command relative to rate response types were demonstrated [30]. Tests were conducted using the large motion system of the DERA Advanced Flight Simulator for an approach and landing task in degraded visual conditions. The attitude response configurations resulted in significant alleviation of the workload associated with the stabilisation task when flying through moderate levels of turbulence. One of the design challenges associated with conferring strong levels of stability to achieve powerful disturbance rejection is how to achieve this while maintaining adequate levels of agility for the pilot to 'break free' in emergencies. This will be particularly relevant to future full-authority fly-by-wire and actively controlled rotorcraft, but design rules for partial authority systems are also required.

The reduced situational awareness associated with flight in degraded visual conditions makes flight in disturbed conditions close to structures particularly hazardous. In ADS-33, requirements for flight in degraded visual conditions refer to the useable cue environment (UCE). In moderately degraded conditions (UCE 2), ADS-33 states that an attitude response type is required to provide Level 1 handling qualities; the results from [30] confirm this for the civil helicopter hover recovery task. In more degraded conditions (UCE 3), ADS-33 states that a translational rate command response type is required to confer Level 1 handling. Basically, as the visual cues degrade, more stability augmentation is required – first attitude stability, then flight path stability – to relieve the stabilisation workload and allow the pilot to concentrate on the guidance task. Ultimately, a combination of visual cue augmentation and stability (or response type) augmentation will be required to ensure safe flight in severely degraded visual conditions. Improving the UCE and providing the pilot with a better awareness of future state are all part of giving the pilot the better situational awareness so critical to ensuring safety as operational restrictions are lifted.

5.2.4 *Handling and performance requirements*

Several references have been made to helicopter handling and performance requirements in this section, and particularly to the military standards – ADS-33 [23] and Def Stan 00-970 [25]. Such standards aim to ensure that helicopters are designed and built so that their behaviour will not compromise operational capability or, more specifically, that the flight envelope will not be restricted by handling deficiencies. The holistic approach taken in ADS-33 has been recommended as the basis for the development of new civil helicopter requirements, particularly the use of mission task elements to develop criteria for Level 1 performance standards. Helideck operations, particularly in degraded visibility and/or environmental conditions, represent a special case in this regard. As piloting aid technologies are developed or transferred from similar military applications, including control and visual cue augmentation systems, there will be a real need for design guidelines to ensure that potential improvements in operational capability at offshore helidecks are realisable. Such guidelines could address aspects like the relationship between thrust margin/heave rise times and gust strength/gradients, the design parameters of a stability augmentation system as a function of turbulence levels, and the important design features of a head-up/helmet mounted director display system as a function of the useable cue environment.

5.3 Engine Response to Environmental Disturbance

5.3.1 *Sources of disturbance*

The high-power production capability of offshore oil and gas installations inevitably gives rise to releases of gaseous material either in the form of exhaust from gas turbine plant or hydrocarbon mixtures resulting from some malfunction in the production system. For a helicopter operating in close proximity to such an installation, there is a risk that ingestion of such gaseous material will have a detrimental effect on engine performance. The effects of these disturbances are largely transient in nature, but pose a potentially serious hazard to safe flight in situations where the scope for recovery may be limited.

5.3.2 *Bulk temperature increase and spatial temperature distortion*

The aerodynamic matching of the compressors and turbines within helicopter power-plants is sensitive to the bulk inlet air temperature. When air inlet temperatures are increased, for example by ingesting the products of combustion from a gas turbine exhaust plume, a rapid re-adjustment of air and gas flows takes place within the engine. Spool speeds may also change, albeit with a slower response, and the engine controller will also make changes to the engine inputs (fuel and perhaps variable guide vane angle) to suppress disturbances to the controlled parameters (e.g. torque match and main rotor speed) as far as limitations will allow.

There will also be a modification of the oxygen levels and thermodynamic properties of the inlet air as a consequence of the inclusion of exhaust gases, but generally this will have a second order effect on the engine compared with the temperature effect.

Spatial temperature distortion at the engine face will also reduce the surge resistance of the engine. Both the intensity of the temperature variation and the extent of the engine face affected influence the loss of surge resistance. Different engine designs are likely to be affected differently. The state of engine repair and cleanliness of the compressors are additional factors influencing the likelihood of surge.

A thermodynamic simulation of an engine cycle approximating to the RTM 332 engine has been used to determine the effects on power output of changes in inlet temperature in the range 2°C to 10°C over a time step of 3 seconds. The simulated temperature changes were ramped in at rates less than 1000°C/s which was sufficient to preclude surge within the simulation. However, spatial effects, which would be encountered in a real situation, were beyond the scope of representation in this particular simulation. To prevent bulk rate of change of inlet temperature being a significant cause of surge margin loss, rates should be constrained to much less than 1000°C/s.[7] The outcome of the simulation, therefore, is simply a transient loss of power over the duration of the time step.

The results of the simulation are shown in Figures 7(a) to (c). Each set of curves shows the same general characteristics with an initial loss of power in the form of a spike measured in milliseconds, followed by a recovery to a reduced power level within a time interval of approximately 1.5 seconds. The reverse sequence occurs at the end of the original time step.

The impact on the hover/thrust margin has been taken as that corresponding to the loss of power represented by the steady-state level achieved after the initial 1.5 second transient. For the cases represented in Figures 7(a) to (c), the predicted power losses are shown in Table 2.

It is clear that the percentage loss of power/°C is virtually constant over the range 2°C to 10°C at 0.17% per °C which corresponds to a thrust margin loss of 0.11% per °C.

It should be noted that, in reality, helicopter engines are governed so there is not a loss of power unless the limits of the governor are reached. The loss in performance therefore amounts to a loss in power margin.

Bulk Inlet Temperature Change in °C	Percentage Loss of Power	Percentage Loss of Power/°C
2	0.39	0.19
5	0.78	0.16
10	1.65	0.17

Table 2: Effect of a simulated step change in bulk inlet temperature on engine power output

[7] See page 70 (in Section8.7.1) and Report 154 in Annex 4 for an example of an engine surge occurrence almost certainly due to ingestion of hot gases.

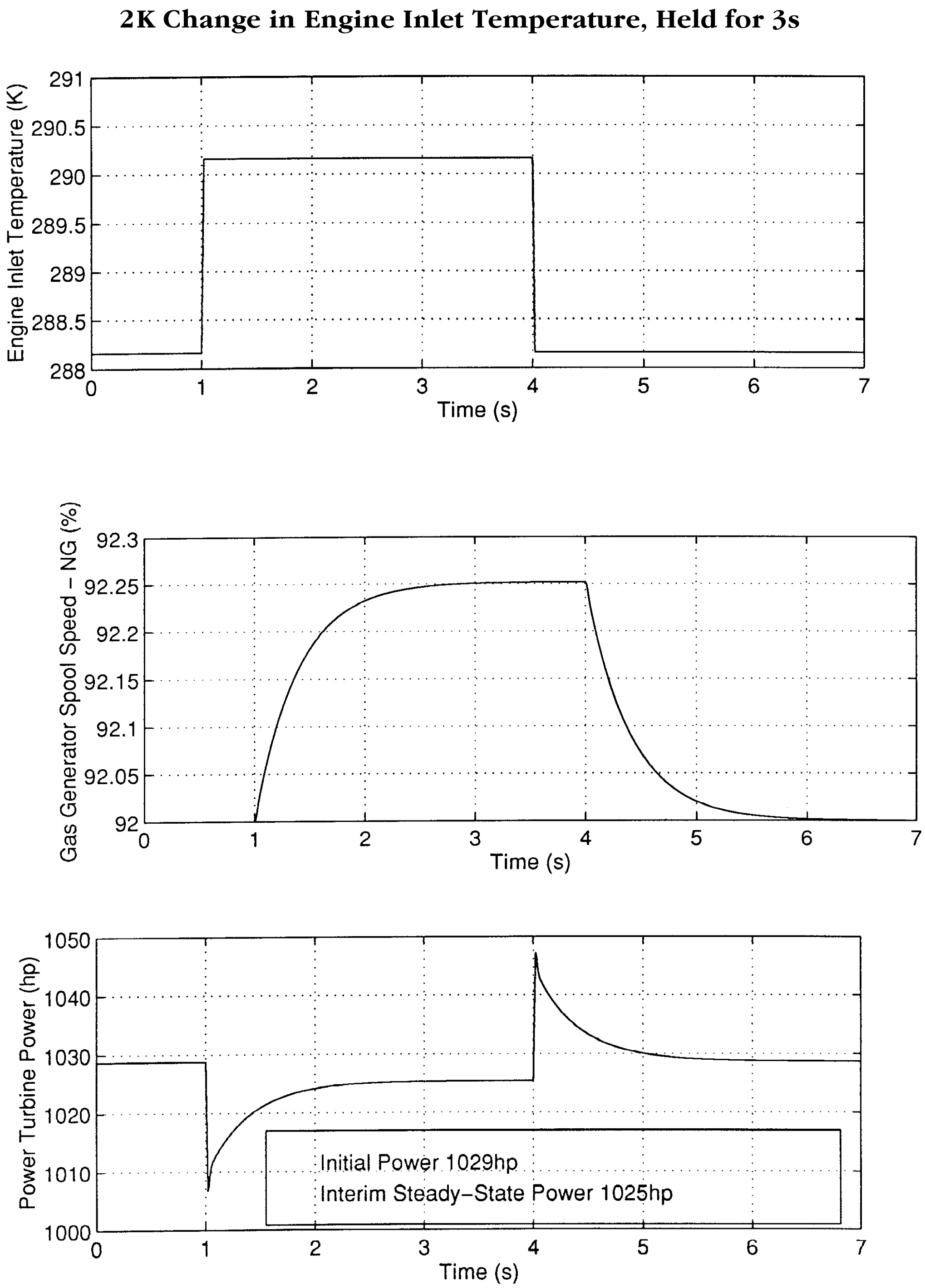
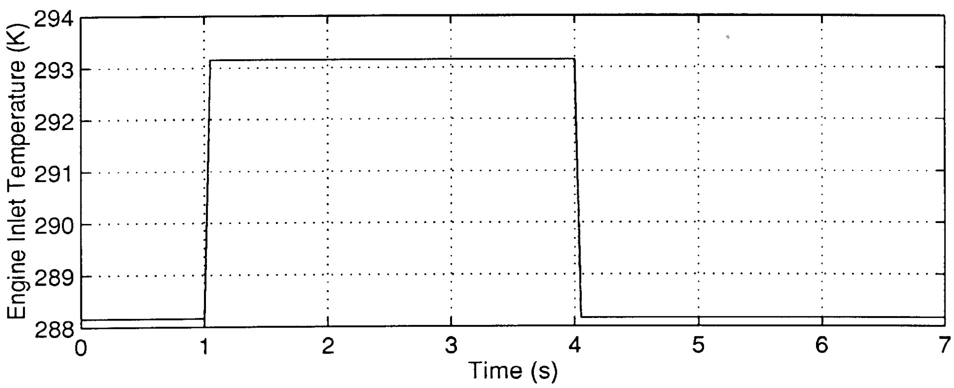
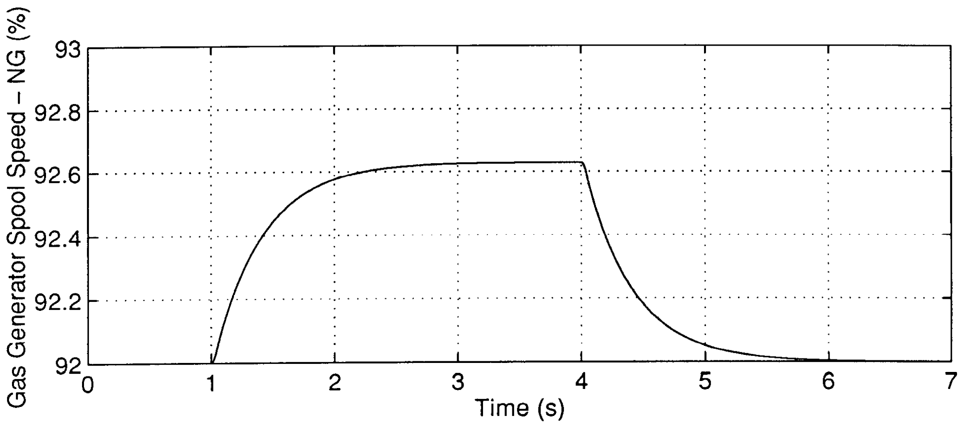


Figure 7(a): Simulated response of a typical helicopter engine to a 2°C change in bulk inlet temperature

5K Change in Engine Inlet Temperature, Held for 3s





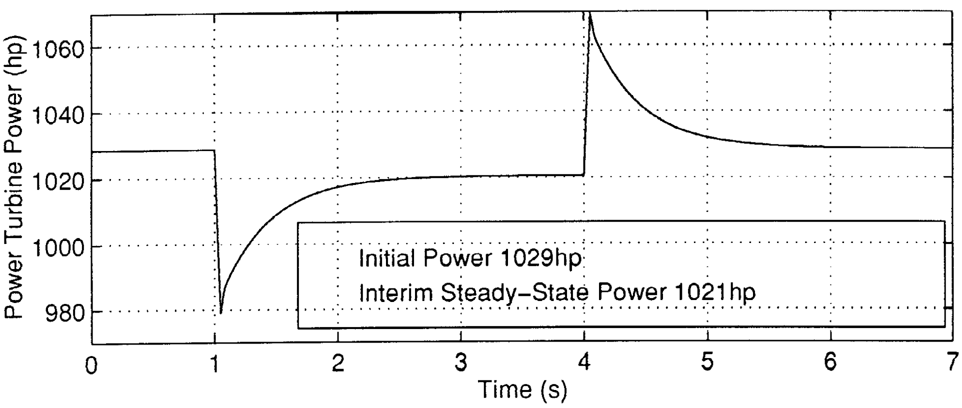


Figure 7(b): Simulated response of a typical helicopter engine to a 5°C change in bulk inlet temperature

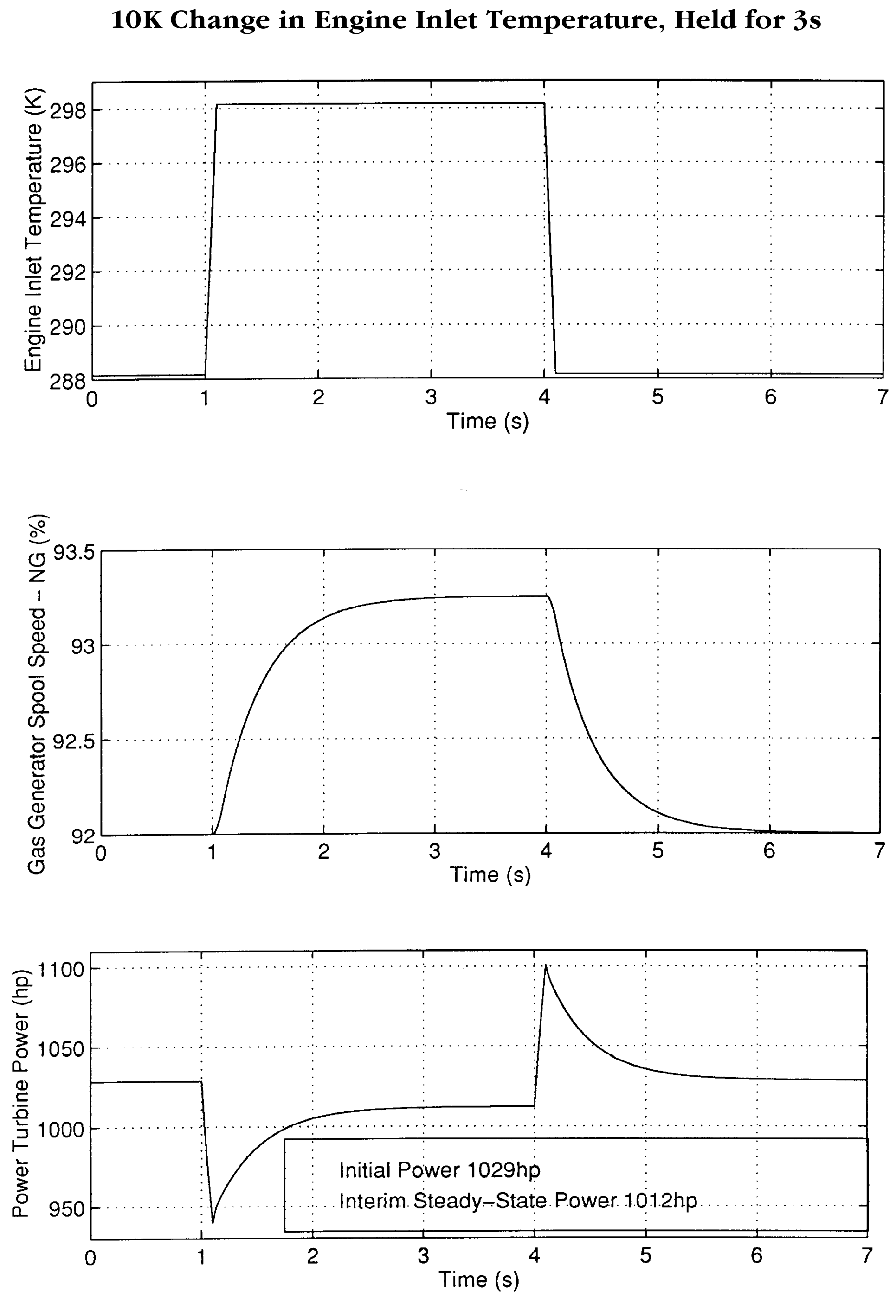


Figure 7(c): Simulated response of a typical helicopter engine to a 10°C change in bulk inlet temperature

5.3.3 *Ingestion of hydrocarbon mixtures*

Flammable gases, whether or not they are within flammability limits, may contribute to energy release within the gas turbine combustor. This will be particularly true for the combustor primary zone through which approximately one third of all air will flow. The stability of the engine compressors is affected by the total combustor heat release. During engine accelerations, the level of over-fuelling is constrained to avoid excessive erosion of the surge margin. By way of example, one of the symptoms of engine degradation is acceleration induced surge. Therefore untoward energy release within the combustion will reduce compressor surge margin. It is true that the engine control will respond to counteract the effects of the un-metered energy but only after its effects become evident at the engine control sensors, and then only within the controller bandwidth of typically 10Hz (fuel regulation).

Without detailed study, it is not possible to determine whether sufficient flammable gas can be entrained with adequate rapidity to precipitate a compressor surge. It is certain however, that such gases, in combination with temperature transients and temperature distortion, would serve to increase the likelihood of surge.

In an attempt to quantify the possible scale of sensitivity it may be said, in broad terms, that an engine in a fully established acceleration will consume about 20% more fuel than at the same gas generator speed in steady state and suffer a halving of the surge margin. Steady state overall air fuel ratio of between 40:1 and 50:1 is typical. It can be shown that 10% LFL [8] is equivalent to 10% more fuel, and so if the hydrocarbons contained in the intake air are well below the flammability limit (e.g. 10% LFL) they would alone represent only a moderate over-fuelling and cause acceleration about half maximum and attendant loss of surge margin during the brief period of accommodation by the engine controller. On this basis, a limit of 10% LFL unburned hydrocarbons within the operating environment would appear to be safe from the engine handling point of view when encountered in isolation. It will, nevertheless, produce noticeable disturbances and reduce the engine tolerance to other environmental effects with which it is highly likely to be associated.

5.4 Pilot Information Displays

5.4.1 *Information requirement*

Helicopter aircrew operating to offshore platforms often face a challenging task in the final part of their journey when they have to perform a landing on a small and often difficult to find helideck. There are a number of potential problems they may encounter including lack of visual cues, turbulence from air circulating around the platform superstructure and the effects of the emissions of hot exhausts or cold gas mixtures.

Specific flight procedures and limitations, resulting from wind-tunnel testing and pilot experience, are applied to some offshore installations where the combined effects of adverse wind flows and the effects of exhaust plumes/flares are likely to be present.

During the flight planning stage, it is vital for the aircrew to have access to as much relevant information about the offshore landing site as possible. There may also be some benefit in displaying some of the relevant measured/known parameters to the aircrew in real time to increase their situational awareness, and hence make the approach/landing phase safer and easier.

There are two categories of information aircrew would like to have access to when they operate to offshore helidecks. Firstly, there is the information that is 'fixed' such

[8] Percentage LFL assumed to be by mass, not volume.

as the position of the platform, where the helideck is in relation to the platform layout, how big the deck is, what hazards (including gas plumes) are present etc. This sort of information is distributed in publications and is referred to as and when required.

The second category is the 'variable' information that is particularly relevant for the final approach and landing phase. This includes information on the wind direction and speed, and atmospheric pressure and air temperature which can be measured using known devices and techniques. There are other 'variable' parameters that are not so easy to measure. On some platforms hot exhausts are located in the vicinity of the helideck. If these are operating around the time a helicopter is to land or take off, then it would be useful to indicate this information to the aircrew. The turbulence created by the wind moving through the superstructure may also have an effect on the operation of the helicopter which can also be regarded as 'variable' information needed by the aircrew.

In summary the information that is required to be displayed is:–

- wind speed,
- wind direction,
- air temperature on the helideck,
- air pressure over the deck,
- state (on/off) of hot air exhaust, and
- flow of air around the helideck.

5.4.2 *Environmental sensor systems*

Current methods for showing/ measuring wind speed and direction in the vicinity of the helideck include windsocks, wind birds, anemometers and complex optical systems such as LIDAR. Devices for measuring air temperature and pressure are widely used and available.

There are a number of possible methods of displaying the information listed in 5.4.1. Section 5.4.3 gives an indication of some of the technology that is currently available and could be exploited for the offshore helideck application.

5.4.3 *Helideck mounted information display*

(a) Current technology

Outdoor electronic information displays are being used in an increasing number of commercial applications including roadways and sports stadia. There are a number of technologies that can be used on the face of the display. Some of these are described below.

- **Light Emitting Diodes** – LEDs are relatively cheap to buy. They have long lifespans and the power requirements are low. In recent years there have been a lot of changes and improvements in LED technology. Research is under way to produce LEDs with wider viewing angles, better and purer colours and higher intensities, thus making this technology more suitable for outdoor day and night applications. The LEDs can be limited to certain areas of the display (e.g. for a fixed number of characters or a specific shape) or they can be arranged to cover a full matrix over the display surface. The latter arrangement can allow variable messages as well as pictorial information to be displayed. A multi-colour LED matrix display can also be used to show video pictures. The resolution and overall luminance of the display is affected by the packing density of the LEDs.

- **Fibre Optic Displays** – Fibre optic displays are presently used in road sign applications. One (or more) lamp source(s) can be fitted with a bundle of fibre optic cables which can then transmit light from the source to the surface of a display. To enable the message/ picture to be changed, a shutter system needs to be fitted to the front of the fibres to allow certain fibres to show light and others to be occulted. Having a small number of light sources is beneficial when the maintenance effort is considered. The colour and luminance level of the display depends on the type of lamp used, and viewing angle requirements can be met by careful choice of fibres.

- **Reflective Discs** – Small rotating discs which show a coloured reflective or black side can be controlled electromagnetically to define symbols or characters. This is another type of display that can be seen in roadway applications and is often used for destination signs on buses. During the day time, and particularly in high ambient lighting conditions, these discs reflect sunlight and are very conspicuous even at wide viewing angles. The discs cannot transmit light and therefore cannot be seen during the night unless light is reflected from them. One method of making the display suitable for night time is to combine it with LED or fibre optic technology. Small apertures can be cut in the discs to allow light from LEDs or fibre optics to be seen.

(b) Benefits to offshore operations

The displays can be used to present the required environmental parameters either in textual form or pictorial form or combined textual/pictorial form. For example, the wind direction can be shown by an arrow and the speed can be shown with digits.

The display could show information other than environmental parameters such as free text (e.g. name of platform, other messages for aircrew). A sophisticated system is feasible which, using suitable sensors (GPS, RADAR or radio ranging), could provide the input to an aircraft positioning display to help the pilot maintain the desired angle of descent, into wind, clear of obstacles, and land the aircraft precisely on the required spot.

The location and dimensions of a helideck-based information display should be carefully selected so that it can be seen by the pilot during the approach, landing and take off phases without presenting an obstacle. One idea is to have the display on a rotating base so that it can be faced into the direction of approach.

5.4.4 *Other helideck based visual aids*

(a) Improved windsocks

Aircrew have commented on the lack of visibility of existing windsocks. Action could be taken to improve the location and lighting of windsocks.

(b) Use of existing helideck lighting

Existing helideck perimeter lighting could be re-wired to allow selectable switching of different segments. An application of this would be to flash the lighting on the edges of the deck in which the helicopter should approach. This would take into consideration the wind direction.

(c) Lighting system to indicate status of hot air exhausts

A simple lighting system could be used to indicate the state of the hot air exhaust (e.g. red light shows on, green shows off). The location of the lights should be carefully selected so that they can be seen by the pilot during the approach, landing and take off phases and also they must be designed so they cannot be confused with any other coloured lighting system on the platform.

5.4.5 *Aircraft/pilot mounted displays*

(a) Helmet mounted display

A helmet-mounted display could be used for the final approach and landing phase. The relevant 'variable' environment data (e.g. hot gas exhausts and wind) could be data linked to the aircraft and displayed using suitable symbology. The advantage of such a system is that the information the pilot requires to conduct his operations could be made available just in front of his eyes, allowing him to move his head without losing the information.

(b) Aircraft head-down/head-up display

Head-down displays can be adapted to show 'fixed' platform information as and when required. Currently research is being conducted on Automated Landing Guidance systems which use a number of sensors to create a simple outline of the landing area which is then fused with the real world view through the head-up display. A typical application that is being considered is an aircraft landing at night and in low visibility at an airport. This work can also be applied to helicopters operating to offshore platforms.

'Variable' information on the helideck environment can be data linked to the aircraft and shown on either head-up or head-down displays. As well as the overlay of an outline of the platform and helideck on the outside world view, additional information such as areas where there are hot gases or other hazards can be indicated.

(c) Knee pad display

A knee pad display can usefully provide 'fixed' and 'variable' platform information in a location that could be more suitable than a head-down display in the approach, hover and landing phases. Liquid Crystal technology would be ideally suited for this application.

5.4.6 *Gas cloud detection*

Currently, there is a potential problem with helicopters flying into gas clouds that may occasionally surround oil rigs. These clouds may pose a potential health hazard to human operators or contain sufficient combustible products to upset the effective operation of the gas turbine engines used to power the aircraft. The helicopter may also be an ignition source for such a gas cloud.

The results of a study of the potential helicopter-mounted microsensors that might assist with the detection of such gas clouds is included in Annex 7. However, it is concluded that emission of gas clouds is best detected on the offshore platform itself by the existing warning and safety systems, and means should be found to ensure that helicopter pilots are warned away when such a gas cloud exists (see Section 8.5).

Annex 7 also provides a summary of the current commercial and research status of sensors that may be of use in this application.

6 CAP 437: DESIGN AND SAFETY CONSIDERATIONS

The earlier sections of this report have provided 'state-of-the-art' assessments based on a review of helicopter operations, a description of the environmental hazards involved and an analysis of helicopter responses to particular types of disturbance.

In this next section, the aim is to take a critical look at the environmental criteria specified in CAP 437 and to both review their applicability in the light of current knowledge, and to make recommendations for changes and additions where appropriate.

It should be noted that this section is based on the Second Edition of CAP 437 [9] dated December 1993. A new Edition of CAP 437 [11] was issued during the project, dated October 1998, which incorporates a number of this project's recommendations. Footnotes have been added throughout this section to indicate where the relevant changes have already been made in the Third Edition of CAP 437.

6.1 The Role of CAP 437

The version of CAP 437 published by the CAA in 1981 [10] provided a comprehensive set of guidance notes on offshore helicopter landing areas although initial draft criteria were in existence as far back as 1964. With a series of updates, CAP 437 has been the main instrument controlling the design of helidecks on offshore oil and gas installations for the past 17 years. There was an update in 1993 [9] but this only involved a very minor change to the section dealing with environmental criteria. In publishing CAP 437, the CAA's intention was simply to establish basic criteria and minimum standards for offshore helidecks. It is the CAA's guidance on the application of International Standards and Recommended Practices, agreed by ICAO, concerning offshore helicopter landing areas, and the guidance is used primarily so that *helicopter operators* can satisfy themselves that helidecks are suitable for purpose, in accordance with the aviation legislation. In practice, however, the offshore Industry has treated CAP 437 very much as a design guide in the absence of alternative authoritative documentation.

One recommendation included in CAP 437 that does not seem to have been adopted is that of emitting visible smoke from gas turbine exhaust outlets during helicopter operations to assist pilots in locating and avoiding the hot plume[9]. This is, however, more of an issue for the operator of the installation rather than for the designer.

Implicit in the present situation is the assumption by the Industry that compliance with CAP 437 is sufficient to satisfy the requirements of the current safety-case regime. It has emerged from discussions with the HSE that, although present safety-case requirements include provision for dealing with fire and explosion following a helicopter accident, there appears to be no particular requirement to consider helicopter safety just prior to landing or immediately following take-off. This is seen as a serious flaw in the present safety review procedure since difficulties in the landing or take-off phases are likely to be a contributory factor in any accident scenario.

[9] A study, initiated by the CAA and HSE, is currently underway to investigate the feasibility of visualising gas turbine plumes on offshore installations.

Against this background, this report seeks to review the origins of CAP 437, to consider the influence that it has had on helideck design and to propose possible revisions to the environmental criteria based on the experience gained over the past 17 years, particularly that originating from the many wind-flow studies that have been undertaken.

A point that has been noted from discussions with HSE and CAA representatives is that, although a significant amount of relevant environmental data has been produced from wind-flow studies for design purposes, very little of this data appears to have found its way to the helicopter operators. This is despite the fact that there is a formal procedure for notifying non-compliances, operated jointly by the CAA and the BHAB Helideck Sub-Committee. This takes the form of the Installation/Vessel Limitation List (IVLL) [18] which is updated on a regular basis and issued to helicopter operators.

In view of the important issues raised above, namely that the Industry treats CAP 437 as a design guide and the lack of any clear directive from the HSE regarding the safety-case implications of helicopter operations, it seems appropriate to consider what additional regulatory documentation might be needed to supplement CAP 437. For the purposes of this report however, the status and general format for CAP 437 is assumed to remain unchanged. Any new documentation, whether a design guide or changes to the HSE safety-case requirements, are seen as separate issues which will need to be addressed by both the CAA and the HSE in the longer term.

6.2 Origins of the CAP 437 Environmental Criteria

The version of CAP 437 issued in 1981 [10] included a section on 'Air turbulence and temperature gradient'. The origins of the specified threshold criteria are not documented, but they were no doubt included to guard against problems that had been encountered by pilots with some early offshore platforms due mainly to badly located helidecks. Two sources quoted as references at the time were reports by Davies et al, one entitled *'The nature of airflows over offshore helidecks'* [20] and the other *'Wind-tunnel investigation of the temperature field due to hot exhaust of power generator plants on offshore platforms'* [21]. These reports laid the groundwork for much of the subsequent wind-tunnel testing commissioned by the Industry to demonstrate compliance with the criteria specified in CAP 437.

The environmental criteria adopted in 1981 have remained substantially unchanged over the past 17 years. The principal recommendation was for a limitation on the component of vertical wind speed at main rotor height to be no more than ±0.9 m/s for winds up to 25 m/s. The reason for adopting 0.9 m/s rather than 1.0 m/s is not clear, but it is possible that it arose simply as a conversion from 3 ft/s into ISO units. It has also been suggested that the 2-degree angle of incidence represented by a vertical component of 0.9 m/s combined with a free wind speed of 25 m/s may have had some bearing on the matter.

The consequences of flying into a hot gas turbine exhaust plume were clearly recognised as a potential hazard from the outset, although there appear to have been relatively few cases where such an event could possibly have been responsible for a loss of control [4]. The criteria set in 1981 introduced a threshold ambient temperature rise of '2° or 3°C'. Again, the precise origin of this criterion is not known, but it is believed to relate to a loss of lift capability equivalent to the weight of one passenger and, in any case, 2°C equates to the resolution of the Weight

Altitude and Temperature (WAT) charts used by pilots to determine the payload for a given set of environmental factors.

With hindsight, it is fair to say that engineering judgement appears to have been applied to good effect. The fact that the same criteria were carried forward into the revised version published in 1993, virtually without change, underscores the need for a thorough review.

6.3 Current Criteria and Their Application to Offshore Helideck Design

The full text of the Second Edition of CAP 437 [9] headed 'Air turbulence and temperature gradient' is reproduced in Annex 1. The relevant criteria can be summarised as follows:–

(i) A recommendation for a limitation on the vertical component of wind speed over the helideck at main rotor height to within ±0.9 m/s for wind speeds up to 25 m/s.

(ii) A recommendation that the helicopter operator be informed if the ambient temperature is increased by more than 2°C. It is worth noting that in this case, the criterion applies both *'in the vicinity of the flight paths and over the landing area'*.

These two criteria have had a significant influence both on the design of helidecks and on the elevation and positioning of gas turbine exhaust outlets. For design purposes, the recommendation relating to ambient temperature rise is generally interpreted as a requirement to avoid, as far as possible, ambient temperature rises greater than 2°C above ambient occurring at heights up to 15 m above the helideck.

Since designers of offshore installations have no ready means for predicting wind-flow and temperature effects, it has become customary to engage the services of a consultant with access to a suitable wind-tunnel test facility. Considerable time and effort (and cost) has been expended over the past 15 years in attempting to satisfy the two basic environmental criteria specified in CAP 437.

These studies have resulted in a number of recognisable design features.

(i) Helidecks are normally mounted in an elevated and well-exposed location above the accommodation module.

(ii) The helideck is elevated above the accommodation module to provide a clear air gap of between 3 and 5 m.

(iii) Gas turbine exhausts are generally vertical with outlets between 15 and 20 m above the level of the helideck.

More detailed consideration of the issues affecting helideck design is to be found in [17].

Even with both of these features present, it is often not possible to demonstrate complete compliance with the threshold criteria, and compromises have had to be adopted. These have generally involved an assessment of the percentage frequency (or number of days per year) that the criteria are likely to be exceeded. Whether action is taken to restrict flying operations on those occasions when the criteria are exceeded is a matter for the helicopter operator, and will generally be dictated by experience gained by pilots as represented in the appropriate IVLL. Restrictions are not normally imposed on the strength of wind-tunnel studies alone, as reports on studies commissioned by platform designers have generally not found their way through to the helicopter operators, despite the fact that there is a specific recommendation in CAP 437 to this effect.

6.4 Limitations and Difficulties With the Current Criteria

Difficulties have arisen in the application of the current criteria to the environmental data obtained from wind-tunnel studies and it has been necessary to interpret the data in a way that is compatible with the criteria.

This section of the report is therefore principally concerned with the key environmental parameters identified in CAP 437, namely criteria both on the vertical wind-speed component and ambient temperature rise over the helideck. Although both of these parameters can be obtained from wind-flow studies, neither is readily identifiable as such by a pilot during a landing or take-off manoeuvre. A recent survey based on pilot responses to a questionnaire on workload and safety hazards [5] rated ‘turbulence around platforms’ as a very significant hazard. One of the principal problems of correlating pilot experience with the results of wind-flow modelling studies is that anything that causes a helicopter to deviate from its chosen flight path tends to be described by the pilot under the generic term ‘turbulence’.

At this point, it is probably appropriate to define what is meant by turbulence and a related phenomena generally described as wind-shear. Both are, in fact, features of the wake region downwind of an obstruction which in practice could be the whole installation or a particular major component such as a drilling derrick.

(i) Turbulence is best described as a series of eddies covering a wide range of size and frequency which are carried downwind, and which dissipate over a distance of some 10 or 20 structure widths.

(ii) The natural wind is itself turbulent particularly in close proximity to the ground or sea surface. However, in this case the rate of dissipation is matched by the rate of generation through the shearing action at sea level. The eddy sizes and frequencies are, in general, several orders of magnitude greater than those found in the lee of an obstruction.

(iii) Wind shear is an effect which occurs at the boundary between a wake region and the undisturbed wind flow. It is characterised by a rapid change in the along-wind component of wind speed which separates the reduced mean wind speed in the wake region from the undisturbed free wind. This is often referred to as a shear layer.

A pilot encountering a hot gas turbine exhaust plume may also describe its effects as ‘turbulence’. The effects of flying into such a plume will be felt as both a loss of engine power and a loss of lift through a reduction in air density. As these effects tend to be intermittent, particularly at the boundary of the plume, they are likely to be interpreted by a pilot as turbulence although there will normally be a smell associated with the exhaust plume which should alert the pilot to the true nature of the problem.

The following discussion relates to the experience gained in applying the current threshold criteria to data obtained from wind-flow studies. Such studies are almost invariably conducted in a wind tunnel using a scale model of sufficient detail to accurately reproduce full-scale wind-flow conditions.

6.4.1 *Wind-flow criteria*

The basic procedure generally used to evaluate the wind flow over a helideck involves a so-called 'polar scan' in which measurements of longitudinal and vertical components of wind speed are obtained at three or four heights above the landing spot for a full range of wind direction. The height interval is generally 5 m, with a wind-direction interval of between 10° and 15°.

Polar plots of the vertical wind-speed component are then obtained at each height for a free wind speed of 25 m/s corresponding to the height of the helideck. Almost invariably, there is a sector within which the vertical component exceeds the recommended threshold of ±0.9 m/s. The standard procedure is then to vary the air gap beneath the deck in an attempt to achieve compliance with the criterion. Although it is generally possible to reduce the vertical component in this way, there is often a residual non-compliance.

If other remedial measures prove ineffective, then a further step can be taken which involves recognising that wind speeds of 25 m/s occur relatively infrequently and maybe not at all for the sector exhibiting the non-compliance. Wind-speed statistics for the location of the platform can be used in conjunction with the wind-tunnel data to predict the percentage frequency for exceedance of the threshold criterion.

In locations other than the North Sea, the wind climate may be sufficiently benign to result in a prediction of zero exceedance. In such a case, the helideck design would be accepted as operationally acceptable.

In the North Sea however, a typical platform is likely to exhibit a frequency of exceedance of at least 5% overall. This implies that for more than 18 days per year on average, there are combinations of wind speed and direction for which the ±0.9 m/s threshold can be exceeded.

The current assessment procedure is limited to the vertical component of wind speed although further data in the form of the longitudinal component of wind speed and the level of turbulence are also generated by the wind tunnel tests at the same time. For a well exposed helideck both of these parameters will remain relatively constant for a wide range of wind direction, although significant changes can occur for wind directions where there is an obstruction upwind of the helideck. The principal obstructions are drilling derricks and groups of gas turbine outlets, and it is significant perhaps that pilots have reported turbulence as a problem in such situations. Clearly, there is an opportunity to make use of this additional data provided that appropriate criteria can be developed.

6.4.2 *Ambient temperature criterion*

The procedure used to evaluate the ambient temperature rise over a helideck caused by a hot gas turbine exhaust plume will generally rely on the modelling of the hot plume by a mixture of gases at ambient temperature, and chosen to have the same density as the hot full-scale plume. Dilution of the model plume with distance from the source is then used as an analogue of the decay in temperature.

Predictions of plume temperature are obtained from measurements of concentration, generally in a plane through the landing spot normal to the direction of the wind. For a wind direction which carries the plume across the helideck it is possible to identify the position of the plume in relation to the helicopter flight path as a series of concentric contours of constant temperature.

For a conventional vertical facing outlet, the height of the plume above the helideck will reduce with increase in wind speed, although increased mixing at higher wind speeds has the effect of cooling the plume more rapidly so that temperatures are diminished as wind speed is increased.

There are, however, a number of problems in assessing the significance of the results of such tests in relation to the threshold criterion:–

(i) The present criterion does not specify a height above the helideck below which the ambient temperature should not exceed the 2°C threshold [10].

(ii) Due to the nature of the mixing process, the ambient temperature rise within the plume boundary is very non-steady. At the outer fringes of the plume for example, the short-term temperature rise over a 3-second period can typically be five times the mean time-averaged value. This raises the question as to what time interval to apply to the 2°C[11] ambient temperature rise. In the example given above, a location recording a mean time-averaged temperature rise of 2°C might expect to experience short-term rises of around 10°C.

[10] The Third Edition of CAP 437 (October 1998) now specifies that the 2°C threshold should apply up to a height above helideck level that takes into consideration the airspace required above the helideck to accommodate helicopter landing and take-off decision points.

[11] The Third Edition of CAP 437 (October 1998) now specifies that the averaging period for the 2°C temperature rise threshold should be 3 seconds.

7 THE REGULATORY ENVIRONMENT AND THE SAFETY CASE REGIME

7.1 The Regulatory Environment

Helicopter operations to offshore oil and gas installations are subject to two principle regulatory authorities, the Civil Aviation Authority (CAA) and the Health & Safety Executive (HSE), Offshore Safety Division. CAA regulates aviation legislation. HSE regulates health and safety law.

In addition to co-operating with other government agencies with a role to play in offshore safety, CAA and HSE work closely together on offshore helicopter issues. These include:

- policy development
- research
- operational matters
- accident and incident investigation (in conjunction with the AAIB)
- development of guidance for industry

The CAA Safety Regulation Group is responsible for regulating the airworthiness and operational safety of aircraft, including its passengers.

Under the Civil Aviation Act of 1982, CAA is responsible for the Air Navigation Order (ANO). This legislation governs the airworthiness of helicopters and the technical and operational requirements which must be met. It also lays down the requirements for the issue of an Air Operator's Certificate which helicopter operators must hold.

CAA has no duty to license offshore helidecks. However, CAA produces guidance (CAP 437) [9] which includes criteria for helidecks to meet, and other information which enables helicopter operators to comply with their legal obligations.

Helicopter operators have a duty under the ANO to conduct flights only to suitable landing areas. They are also responsible for the safety briefing of passengers and for providing certain personal safety equipment aboard the aircraft.

The Health and Safety at Work Act 1974 is the main legislation providing for the health and safety of workers offshore. Under the Act, there are several regulations which deal with specific requirements relating to helidecks on offshore installations and to helicopter operations.

Installation owners and duty holders are responsible for the safety of the entire installation, including the helideck and helideck operations. They are required to ensure that the helideck operating environment is such that helicopter operators can discharge their duty. Amongst other things they have direct control over the physical characteristics of the helideck and surrounding environment, except of course, the prevailing meteorological conditions.

7.2 The Safety-Case Regime

The Offshore Installations (Safety Case) Regulations 1992 (SCR) (SI 1992/2885) [31], among other things require installation owners and duty holders to identify all hazards which could cause a major accident, including helicopter accidents, and to take measures to reduce the risks to as low as is reasonably practicable (Regulation 8).

The Safety Case Regulations are supported by other legislation relating to helidecks and helicopter operations. They include the Offshore Installations and Pipeline Works (Management and Administration) Regulations 1995 (MAR) (SI 1995/738) [32], the Offshore Installations and Wells (Design and Construction, etc.) Regulations 1996 (DCR) (SI 1996/913) [33] and the Offshore Installations (Prevention of Fire and Explosion, and Emergency Response) Regulations 1995 (PFEER) (SI 1995/743) [34].

The approach taken when making these Regulations was to set objectives. The legal objectives are then expanded further in guidance on the regulations. One key guidance document is the Assessment Principles for Offshore Safety Cases [35].

It is noted that with respect to helicopter operations the guidance on Safety Case Regulations is focused on the hazards and risks to an installation and its personnel from impacts by aircraft. It does not explicitly encompass the hazards and risks to a helicopter and its passengers from the installation and its processes.

8 DISCUSSION

Each of the preceding sections of this report has raised a number of different issues which are now drawn together in the following sections to provide a comprehensive review of the findings of the whole study.

8.1 Environmental Hazards to Helicopter Operations

The Safety Regulation Group (SRG) of the Civil Aviation Authority is responsible for all aspects of safety relating to the operation of helicopters to offshore oil and gas installations located in UK waters. It has long been recognised that there are particular hazards associated with helicopters operating in close proximity to offshore installations. The principal hazards are disturbed airflow and local ambient temperature rise due to exhaust outlets on the installation. An incident in 1995 [4], involving a heavy landing on the Claymore Accommodation Platform helideck has highlighted the potential for a major accident.

A basic review of the procedures and practices currently employed for offshore helicopter operations has shown that:

(i) Improved mandatory occurrence reporting (MOR) indicates that the level of hazard associated with environmental factors may be greater than previously recognised. It is suspected, however, that there are a large number of ‘near miss’ situations which, for various reasons, do not get reported through the MOR system.

(ii) The lack of a comprehensive helideck design guide has resulted in designers of helidecks seeking to satisfy the requirements of CAP 437 in isolation, without recognising the need to consider the wider implications of helicopter operations. It is argued that the operational capability (or operability) of a helideck needs to be considered in parallel with its basic design.

(iii) The findings of the pilot survey [5] has shown that, in the opinion of pilots, turbulence contributes to high work load and safety hazards more frequently than any other aspect of offshore helicopter operations. The fact that there is no quantitative criteria for turbulence in CAP 437 is therefore seen as an anomaly.

(iv) Helideck designs are quite frequently the subject of detailed wind-flow modelling studies, the results of which could provide information useful to helicopter operators. The fact that this information is not generally used for this purpose is seen as symptomatic of the relatively poor communications that currently exist between the designers of offshore helidecks and the helicopter operators.

(v) A CAA backed proposal for the routine monitoring of FDR data to detect deviations from normal aircraft behaviour [8] has been identified as a very positive step towards obtaining quantitative feedback on the actual environmental conditions experienced by helicopters operating in close proximity to offshore installations.

8.2 Sources of Environmental Hazard Information

Wind-flow modelling of the environmental situation around a large number of offshore installations has provided detailed information for helideck designers. The principal sources of hazard have been identified as:–

(i) Localised distortion of the airflow around the installation which results in upward or downward air currents over the helideck.

(ii) Disturbed airflow over the helideck in the form of wind shear and turbulence associated with wake regions downwind of either items of local superstructure or, possibly, a complete nearby installation.

(iii) Local increases in ambient temperature in the path of the plume generated by either a gas turbine exhaust or an ignited flare. These sources will normally be associated with the installation itself but may also be due to a nearby unit.

(iv) Concentrations of hydrocarbon gas due to a release from the installation either as the result of an accident or as part of a controlled blowdown procedure.

The lack of quantitative full-scale data seems to have been a serious handicap both in the validation of the wind tunnel testing approach and, more particularly, in gaining acceptance by the helicopter operators of the considerable volume of data that has been produced. A CAA backed scheme for routine monitoring of FDR data [8] has already been welcomed as probably the only practicable approach for obtaining full-scale quantitative feedback.

There have also clearly been difficulties in interpreting offshore platform wind flow modelling reports in terms of helicopter operations, and the development of a standard form of presentation would undoubtedly help industry to make best use of this data.

8.3 Helideck Design Considerations

Helidecks that have been developed with the aid of wind-flow modelling studies show a number of characteristic design features which include well exposed locations to take advantage of the prevailing wind and unobstructed air gaps of at least 3 m below the deck, both of which contribute to the quality of the airflow over the helideck. Gas turbine exhausts are generally arranged to be vertical with outlets at least 15 m above the level of the deck.

It has been observed that the provision for recording and interpretation of wind speed and direction is not necessarily consistent from platform to platform, with the result that there is potential for ambiguity in the data provided to pilots.

The concept of a 'hazard zone' around an offshore installation has been suggested as a basis for advising pilots of the possibility of encountering an environmental disturbance. This could have particular significance in situations where a nearby installation, either permanent or temporary, has the potential to create an additional hazard. In more practical terms, it has been shown that informed flight planning procedures, based on the results of wind-flow modelling studies, could substantially reduce the risk of a pilot encountering handling difficulties due to an unexpected environmental disturbance.

8.4 Helicopter Responses to Environmental Disturbance

A review of helicopter handling and performance in response to various forms of environmental disturbance has provided a common yardstick against which the different forms of disturbance may be judged. This takes the form of a quantifiable reduction in the available hover/thrust margin associated with either a vertical gust or a change in local ambient temperature. Unfortunately, it has not been possible as yet to determine exactly what levels of thrust margin are currently available to pilots under normal operating conditions.

The principal consideration has been the response to vertical gusts. It has been shown that recovery from a gust of 0.9 m/s, as specified in CAP 437, requires a hover/thrust margin of at least 3% in zero wind with a minimal loss of height. The same analysis predicts that, if a 6% hover/thrust margin is available, then it should be possible to recover from a 1.8 m/s vertical gust with a loss of height of well under 0.5m. However, it should be noted that it is unlikely that with current helideck designs a helicopter could ever experience a 0.9 m/s downdraught in the absence of the beneficial effect on thrust margin of a significant horizontal wind component (see section 5.1.4).

Consideration of the effect of increased ambient temperature on engine and rotor performance has also been based on the corresponding reduction in the hover/thrust margin. In this case, the criterion in the current (October 1998) version of CAP 437 of 2°C averaged over 3 seconds has been shown to correspond to a hover thrust/margin of approximately 0.4%. This effect being equally divided between reduction in engine performance, and loss of lift resulting from the change in air density.

The fact that a helicopter draws air downwards through its rotor implies that environmental conditions in the region immediately above the helicopter can affect the performance and handling. This is particularly relevant for the effects of ambient temperature rise, and an assessment by DERA has indicated that the zone in question extends to a height roughly equivalent to the diameter of the rotor.

Typical overall response times for helicopters have been assessed as between 2 and 5 seconds, which implies that short duration disturbances of the order of 3 seconds need to be considered. This is particularly significant in relation to the effects of a hot exhaust plume where quite severe short-term temperature changes can be encountered at the outer edges of the plume.

Helicopter response to turbulence has proved more difficult to quantify due to the range of frequencies (or eddy sizes) that can be encountered. With further investigation[12], it is anticipated that it will be possible to propose a threshold level below which pilots are unlikely to experience problems. For the moment, however, it is only possible to classify the effects of turbulence as indicated in Section 5.1.2.

It is worth noting that turbulence and downdraught will generally be coincident, and although the thrust margin analysis suggests that in realistic wind conditions there will be a large margin of performance to overcome a downdraught, it may be that this simple criterion of 0.9 m/s maximum vertical wind component is effectively

[12] A study to define a permitted level of turbulence has been initiated by CAA and is now underway.

protecting helicopters from the effects of excessive turbulence. It should not therefore be relaxed until a properly based turbulence criterion has been derived.

8.5 Some Practical Operational Considerations

Operational information currently available to pilots comes basically from two sources. Aerad plates give physical details of particular installations and the IVLL (Installation/Vessel Limitations List) advises on known hazards. The information supplied may not always be up-to-date so that pilots depend very much on their own individual experience in selecting their preferred landing and take-off strategies. A proposal to combine the Aerad plates and the IVLL into a single source reference for pilots has been welcomed as a step in the right direction.

One practical measure that has not been taken up by the platform operators is the suggestion made in CAP 437 that visible smoke be emitted from the various gas turbine exhaust outlets whenever there is a helicopter in the vicinity. Whilst it seems that there has been a reluctance on the part of the operators to adopt such a measure, it is equally clear that pilots would undoubtedly find it helpful, both in locating potentially hazardous exhaust plumes, and in providing a ready visual indication of the direction of the wind[13].

A review of offshore operational procedures and practices has concluded that the quality of weather and environmental information provided to pilots from different installations is very variable.

Various forms of visual information display under consideration for naval use have also been reviewed but it has not been possible to draw any firm conclusions regarding their applicability to offshore operations. The planned introduction of status lights on offshore installations should provide an immediate means of warning pilots of a problem provided that the use and interpretation of the signals is unambiguous.

Consideration has also been given to the installation of gas leak detection systems on helicopters as a means of warning pilots of the presence of a gas cloud. However, the preferred strategy in the event of a release of gas would be for it to be detected by the platform using the normal gas detection and other safety systems, for the helideck status light system to be activated, and for the pilot to be given an immediate verbal warning by radio to stand off, as part of the appropriate safety procedure.

8.6 CAP 437

The environmental criteria contained in CAP 437 have remained substantially unchanged for over 17 years. During this period, it is recognised that they have played a crucial role in limiting environmental hazards to helicopters operating to helidecks located on offshore oil and gas installations. A review of the working and application of the particular criteria included in CAP 437 has, however, identified a number of short comings and practical difficulties:

[13] A study, initiated by the CAA and HSE, is now underway to investigate the feasibility of visualising gas turbine plumes on offshore installations.

(i) One very basic problem is that the origins of the criteria, developed over 17 years ago, cannot be traced. This has tended to undermine their credibility. Despite this problem, experience has indicated that the original criteria were based on sound engineering judgement.

(ii) Wind-flow studies have shown that the vertical wind-speed criterion of ±0.9 m/s is onerous and that it is generally impossible to achieve full compliance within the constraints imposed on current helideck design. A link has been established between the vertical wind-speed criterion and the available helicopter hover/thrust margin in zero wind.

(iii) The ambient temperature rise criterion of 2°C fails to recognise the time dependence of the ambient temperature change associated with a typical hot plume[14]. Furthermore, no guidance is given in CAP 437 as to the minimum operational clearance that should be allowed in the situation where a plume traverses a helideck[15]. A link between ambient temperature rise and hover/thrust margin may have implications for compliance in the future per (ii) above.

(iv) No quantitative criterion exists to allow the effects of turbulence to be assessed from the results of wind-flow studies [16]. The inclusion of such a criterion would be a significant enhancement to CAP 437.

8.7 Proposals for Revisions to the Environmental Criteria

There is considerable scope for improving the environmental criteria currently included within CAP 437. This could take a number of different forms ranging from simple fine tuning of the current criteria to the introduction of additional criteria covering turbulence and wind shear. There is also the possibility of refocusing the requirements specified in CAP 437 more towards the needs of the helicopter operator rather than just addressing the issues of helideck design.

The strategy for the future revision of CAP 437 rests with the CAA. The purpose of this report is to suggest possible ways forward and, to this end, it is proposed to consider three possible options:–

(i) In the short term, revisions to the criteria presently included in CAP 437 could be made to bring it into line with current assessment procedures. [14, 15]

(ii) In the medium term, additions to the criteria could be made to include turbulent wake effects provided that suitable threshold values can be established.

(iii) In the longer term, a broadening of the scope of CAP 437 could be considered as a means of achieving a better balance between the requirements of the platform designer and the helicopter operator. One means of achieving this

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[14] The Third Edition of CAP 437 (October 1998), issued during the course of this project, now specifies that the averaging period for the 2°C temperature rise criterion should be 3 seconds.

[15] The Third Edition of CAP 437 now specifies that the height above the helideck to be considered should take into account the airspace required to accommodate helicopter take off and landing decision points.

[16] A study to define a permitted level of turbulence has been initiated by CAA and is now underway.

objective could be the introduction of a quite separate 'design guide', as advocated in Section 3.5, to run in parallel with CAP 437 (see Section 8.8 below).

None of these options are mutually exclusive, rather they represent a progressive range of objectives. From the practical point of view, Option (i) could be implemented immediately[17]. Option (ii) will require some further work although it should not be difficult to establish reasonable benchmark criteria based on past experience within, say, six months[18]. The third option breaks new ground in that it will require a more fundamental review of the role of CAP 437 and will take upwards of a year to complete. There is no reason to suppose, however, that any set of environmental criteria developed for use immediately above the helideck could not equally well be applied to the wider field of helicopter operations in the general vicinity of an offshore installation.

8.7.1 *Criteria for vertical wind speed, ambient temperature and hydrocarbon gas concentration*

(i) *Vertical wind-speed component*

The analysis carried out of the response of a typical modern helicopter to the imposition of a sudden downdraught (see Section 5.1 and [36]), has indicated that the current criterion of 0.9 m/s may be conservative. The hover/thrust margin required to recover from an 0.9 m/s downdraught is predicted to be at least 3%, with a minimal loss of height. The same analysis has also indicated that a hover/thrust margin of 6% would allow recovery from a downdraught of 1.8 m/s with a loss of height of no more than 0.5 m.

It is important to establish just what hover/thrust margins are currently available to pilots under normal operating conditions and how these margins are arrived at. When this information is available, it should be possible to review operational procedures and to determine whether any relaxation of the limits on vertical wind speed is possible. This could have benefits in terms of a less restrictive operational regime or make the achievement of a fully compliant helideck less onerous for the helideck designer.

A further revision proposed is that the reference to a free wind speed of 25 m/s be replaced by a requirement to predict the percentage frequency for exceedance of the agreed threshold. This should be based on the full range of wind speed and direction for the location of the platform. Any direction reporting a non-zero frequency should be identified as a non-compliance and a corresponding wind speed and direction recorded as an upper limit for normal flying operations. The result would be a polar plot similar to the SHOLs (Ship Helicopter Operating Limits) currently used for the control of naval helicopter flying operations.

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[17] The Third Edition of CAP 437 (October 1998), issued during the course of this project, now specifies that the averaging period for the 2°C temperature rise criterion should be 3 seconds.

[18] A study to define a turbulence criterion has now been initiated by CAA and is currently underway.

(ii) *Ambient temperature rise*

The analysis carried out of the response of a typical helicopter to a sudden change in inlet temperature (see Section 5.3 and [36]) has indicated a loss of power of no more than 0.17% per degree increase in inlet temperature within a time interval of approximately two seconds. This corresponds to 0.34% for a 2°C rise. A feature of the analysis is the transient response of the engine which exhibits a sharp peak for a fraction of a second followed by a decay to a steady-state value within no more than two seconds. A similar transient effect occurs when the inlet temperature reverts to its initial value except that in this case, there is a corresponding increase in power. These transient effects occur within a time frame which is of the same order as the response time of a typical pilot so that there is a risk that a pilot could easily over react in such a situation.

Very rapid changes in inlet temperature of the order of 1000°C per second can induce surge and possibly engine flame-out. Engine surge has been reported in a situation where a pair of horizontal-facing gas turbine outlets were located just below the level of a helideck (see Report 154 in Annex 4). Whilst in the hover just above the deck, the helicopter was only some 10 m from the exhaust outlets. The spatial definition of the exhaust plumes would have been intense with this proximity to the exhaust outlets. As the exhaust plumes moved past the engine inlets due to air turbulence or helicopter motion, significant temperature distortion could have been encountered. This would have compounded the loss of surge margin due to rate of change of inlet temperature.

It is apparent that in this case there was lack of operational information exchange between the Duty Holder and the Helicopter Operator. This is an extreme case and one that should be avoided in design, or by operational procedures, at all costs.

In addition to the loss of power from the engine, there will also be a loss of lift from the rotor corresponding to the change in air density with increase in temperature (see Section 5.1.6). Taking the change in density as inversely proportional to the absolute temperature, the corresponding loss of lift for a 2°C ambient temperature rise (from 15°C) will be approximately 0.17%. Combining the effects of loss of engine power and rotor lift, the resultant reduction in the hover/thrust margin has been taken as being approximately 0.4% for a 2°C temperature rise. The corresponding time interval within which recovery is possible is only limited by the pilot's response time which is likely to be no more than 1.5 seconds.

The above analysis suggests that the present threshold of 2°C is conservative but, more importantly perhaps, that the time interval over which the temperature change occurs needs to be specified as no more than 3 seconds [19].

(iii) *Hydrocarbon gas concentration*

Concern has been expressed by the CAA over the consequences of a hydrocarbon gas release for a helicopter operating in close proximity to an

[19] The Third Edition of CAP 437 (October 1998), issued during the course of this project, now specifies that the averaging period for the 2°C temperature rise criterion should be 3 seconds.

offshore installation. An assessment carried out as part of this study (see Section 5.3 and [36]) has suggested that a helicopter engine should be able to tolerate ingestion of a hydrocarbon mixture of 10% LFL (Lower Flammable Limit) without undue harm. If it is intended to include a hazard threshold for a hydrocarbon gas cloud as an additional environmental criterion then a level of 10% LFL would seem to be an appropriate figure. [20]

In practice however a release of hydrocarbon which had only diluted to 10% LFL some distance downwind of the source would correspond to a significant loss of containment. For an accidental release in the process area, gas concentrations close to the source would certainly be significantly greater than the low-level gas alarm (normally 20% LFL) so that a series of emergency actions would have been initiated. One of these actions ought to be an immediate alert to any helicopter in the vicinity to stay clear until the emergency has been brought under control in conjunction with the helideck status light system being activated. The environmental hazard due to a gas release is seen therefore as a safety-case issue rather than a matter requiring a prescriptive threshold criterion.

In the case of controlled venting, the release of low levels of hydrocarbon gas should not pose a safety risk to a helicopter in the vicinity of an installation on the basis that it is not a safety risk to the installation itself.

8.7.2 *Criteria to include the effects of turbulence and wind shear*

Information on turbulence either as root-mean-square wind speeds or in the form of spectra is generated from the wind-flow studies currently carried out to quantify the vertical wind-speed component. Without appropriate threshold criteria, however, this information remains largely unused[21].

By classifying on a scale of severity particular situations in which pilots have reported adverse levels of turbulence it should be possible, by comparison with the corresponding wind-tunnel data, to set a criterion for an appropriate turbulence parameter to be used in future environmental assessments.

Strong wind-shear effects can be encountered by naval helicopter pilots during landing and take-off manoeuvres from warships where the helideck is located immediately aft of the main superstructure. For a well exposed helideck on an offshore platform the effects are likely to be far less severe, but there will be some wind-shear effects whenever there is an obstruction such as a clad drilling derrick upwind of the helideck.

The presence of a shear layer can be readily detected in the results for the longitudinal wind-speed measurements produced as part of the wind-flow studies described earlier. In reviewing such results, BMT has adopted a somewhat arbitrary criterion that a polar scan of the longitudinal wind speed should not show a drop of more than 20% due to the effect of an obstruction upwind. Such a situation would undoubtedly show high levels of turbulence so that it is arguable that a turbulence criterion alone could be sufficient, and probably easier to apply.

[20] The Third Edition of CAP 437 now specifies 10% Lower Flammable Limit.

[21] A study to define a turbulence criterion has now been initiated by CAA and is currently underway.

8.8 Implications for the Future of CAP 437 and the Case for a Helideck Design Guide

CAP 437 is regarded by HSE as a key document for guidance on offshore helideck standards within the offshore safety regime, and is referenced for example in [37]. However, it is not clear that CAP 437 is the right instrument for the development of improved helideck design guidance. As noted in Section 6.1, CAP 437 is the CAA's guidance on the application of International Standards and Recommended Practices, agreed by ICAO, concerning offshore helicopter landing areas, and the guidance is used primarily so that *helicopter operators* can satisfy themselves that helidecks are suitable for purpose, in accordance with the aviation legislation. The primary function of CAP 437 is therefore to give guidance to helicopter operators on criteria to be accounted for in Operations Manuals, which is required under UK aviation legislation and by the Joint Aviation Authority (JAA). However, since CAP 437 was first issued in 1981, it has also been adopted as a helideck design guide by the Offshore Industry in the absence of alternative authoritative sources.

Given that CAP 437 is primarily intended for aviators, it is probably not the right instrument for the development of improved and more detailed helideck design guidance for the offshore industry. Helideck design has to date been largely a matter of satisfying the requirements of CAP 437 with very little consideration being given to operational capability of the helideck once installed. A lack of feedback from helicopter operators to helideck designers has also limited the scope for improvements in design.

One possible course of action would be for CAP 437 to continue in its present role as primarily setting minimum offshore helideck standards for the aviation industry, being updated at intervals to reflect expert opinion and the best available information. The other important issues that have been identified, which generally fall outside the present scope and style of CAP 437, suggest there is a need for a separate guidance document. The provision of a comprehensive Offshore Helideck Design Guide would relieve CAP 437 of this responsibility.

The Offshore Helideck Design Guide should examine the issues of helideck design and 'design for operations' in the light of the experience gained offshore over the past 30 years. It should be developed by industry, with the assistance and encouragement of HSE and CAA, and would be an oil industry companion to CAP 437. It would then command the respect of both the designers and the operators, and be supported by the appropriate regulatory authorities.

8.9 Implications for Flight Operations

Control of helicopter operations is another area that has been identified as requiring attention. This is seen as a safety issue and very much related to the present safety-case regime. There is clearly scope for some form of documentation or, possibly, an information system for pilots, designed to improve the safety of helicopters operating in the immediate vicinity of an offshore installation. This could include information for flight planning in relation to environmental hazards, on communications and emergency procedures in the event of an accidental release of gas or on any other matter arising from a review of safety procedures.

It is clear however that there is far more information on environmental conditions around offshore installations in existence than is currently made available for helicopter operations. A separate development could be the preparation of this data in a format suitable for use by pilots.

In its most basic form this could simply be advice on the environmental hazards likely to exist for a given wind speed and direction. A pilot would simply access the appropriate database via a PC located in the crew room, but be free to use his own judgement and experience in deciding what approach or take-off path to follow. A more developed system could take this a stage further and recommend a particular flight path for a given set of environmental conditions.

8.10 The Regulatory Environment

It has been noted in Section 7.2 that in the context of helicopter operations the guidance on Safety Case Regulations is focused on the hazards and risks to an installation and its personnel from impacts by aircraft. The guidance does not explicitly encompass the hazards and risks to a helicopter and its passengers from the installation and its processes. The inclusion of information about these hazards and risks and their mitigating measures should be specifically introduced as part of the Safety Case strategy. Doing so has the potential for providing a significant contribution to the overall level of offshore safety.

There are a number of situations where the actions of the duty holder could be prejudicial to the safety of helicopter operations. These include poorly controlled activities which could adversely affect the wind flow over the helideck, such as basic design or modifications to the topside layout and allowing equipment to be stored under the helideck thereby reducing the effectiveness of the air gap. Combined operations involving a work-over rig or a flotel positioned close to the installation can also have serious implications for the safety of helicopter operations by introducing additional wind-flow and temperature effects as well as encroaching into the obstruction free sector. In addition, there is the issue of the impact of one installation on helicopter flights to another that is nearby. For bridge linked units where more than one helideck is available there may be a choice of which helideck should be used in a given set of circumstances.

An awareness by the Offshore Installation Manager (OIM) of the impact of routine platform activities on helicopter operations can also be important. Gas turbine plumes are largely invisible to a helicopter pilot but can be detrimental to helicopter handling and performance. Information on the operational status of such equipment should always be made available to pilots.

Rare events such as releases of hydrocarbon gas, whether due to an unforeseen accident or as part of a controlled blowdown of process equipment, also represent a hazard to helicopters. Appropriate action by the OIM in promptly notifying a pilot will minimise the hazard involved.

Taken together with the misgivings expressed in Section 3.2 regarding the variable quality of other information supplied to pilots, it is concluded that there is a strong case for ensuring that helicopter operations become an integral part of the design and operations Safety Cases for installations.

In the light of the above it seems that, when preparing Safety Cases, the duty holder should, amongst other things, address the following particular issues:

(i) The development of a schedule of key factors likely to have an impact on the safety of helicopter operations. This should include but not necessarily be limited to:–

- the maintenance of unobstructed air flow over and **under** the helideck,
- consideration of the likely impact on air flow due to changes in the topside layout which could range from temporary storage under the helideck to more permanent changes such as the addition of cladding to the drilling derrick,
- the operation of gas turbine and diesel units in situations where hot exhaust may be emitted into the path of a helicopter,
- flaring and blowdown of flammable gas which may be prejudicial to helicopter operations,
- the location, operation and maintenance of wind recording equipment, and
- combined operations involving another unit in the vicinity of the installation with the potential to disturb the airflow or to emit hot exhaust into the flight path of a helicopter.

(ii) The installation of a system of audit and control which monitors compliance with a set of established operational requirements designed to minimise environmental hazards to helicopter operations.

9 CONCLUSIONS

This has been a very wide-ranging study covering a number of multidisciplinary design and operational issues. Consequently the conclusions are rather extensive. In the following they are mostly presented in the form of short statements. However, the report sections where the explanation and/or justification for each conclusion are referenced in brackets. Recommendations are given in Section 10.

1 The level of occurrences associated with helideck environmental factors may be higher than was previously recognised (3.4, 3.5, 8.1).

2 There are currently no reliable and effective electronic landing aids available for use on offshore installations and offshore helicopter crews have to rely heavily on their acquired skills and experience when approaching, landing and taking-off from offshore installations (3.1).

3 Surveys have demonstrated that, in the opinion of the pilots, turbulence is the most significant source of hazard and high work load in offshore helicopter operations (2.5, 6.4).

4 The operability of offshore helidecks has been consistently overlooked, if not ignored, during the design process. The IVLL, with its many references to non-compliance's and operating restrictions, suggests that helideck operability has not had a high priority during the installation/helideck design phase (3.5).

5 There is sometimes confusion whether the anemometer reading has been corrected, and whether it has been made equivalent to a wind at 10m above the sea (the meteorological standard). For the purposes of providing information to helicopters on the *undisturbed* wind speed and direction in the vicinity of the platform, it would seem logical to provide the information in an agreed standard form (4.1.2).

6 Although helideck designs are frequently subject to detailed flow modelling studies, this information has seldom found its way to the helicopter operators. This is symptomatic of the relatively poor communications that have existed between helideck designers and helicopter operators (3.5, 4.3.1).

7 The development of a standard form of presentation for the results of such wind flow modelling studies would undoubtedly facilitate more effective use of this information by the industry (8.2, 8.9).

8 A project for the routine monitoring of Flight Data Recorder output is likely to be a very positive step toward obtaining quantitative feedback on the effect of environmental conditions in close proximity to offshore installations (2.4, 8.1).

9 The lack of full-scale data has proved to be a serious handicap in gaining acceptance by helicopter operators of the considerable volume of modelling data produced from wind tunnel tests on offshore platforms (8.2).

10 Helidecks that have been developed with the aid of wind-flow modelling and the criteria of CAP 437 show a number of common characteristic features including; well exposed location, at least 3m unobstructed gap underneath, and

gas turbine exhausts with vertical outlets at least 15m above helideck level (4.2, 6.3).

11 The concept of an 'environmental hazard zone' around an offshore platform has been proposed as a basis for advising pilots of the possibility of encountering environmental disturbance (8.3).

12 A review of helicopter performance and handling has identified the hover/thrust margin as a common yardstick against which some of the various types of disturbance may be judged. Unfortunately it has not yet been possible to determine exactly what levels of hover thrust margin are available to pilots under normal operating conditions (5.1, 8.4, 8.7.1).

13 It has been found that the CAP 437 criterion of a 0.9m/s vertical gust requires a hover thrust margin of approximately 3% to maintain a hover over the deck in zero wind conditions. However, it should be noted that it is unlikely that with current helideck designs a helicopter could ever experience a 0.9 m/s downdraught in the absence of the beneficial effects on thrust margin of a significant horizontal wind component.(5.1.4, 8.4).

14 It has been found that the CAP 437 criterion of 2° temperature rise (averaged over 3 seconds) requires a hover thrust margin of about 0.4% for recovery in zero wind conditions (5.1.4, 5.1.6, 8.4).

15 The zone to be considered for gusts or temperature rises should extend to about 1 rotor diameter above the rotor height at typical Committal Point for landing or Rotation Point for takeoff, whichever is the higher (8.4).

16 Typical helicopter response times have been assessed between 2 – 5 seconds, which implies that short duration disturbances of the order of 3 seconds should be considered (5.1.2, 8.4, 8.7.1).

17 Currently there is no established criterion for a safe level of turbulence, and helicopter response to turbulence has proved more difficult to quantify. Further work is needed to establish a criterion (5.1.2, 8.4)[22].

18 Operational information on helidecks currently available to helicopter pilots comes in two forms; the Aerad plates and the Installation/Vessel Limitations List (IVLL). There are currently proposals to combine these (3.2.3, 8.5).

19 The long standing suggestion (in CAP 437) that smoke might be emitted from gas turbine exhausts to make them visible to pilots has not been taken up by the industry. It is clear that pilots would find such a system helpful in both (a) highlighting the potential hazard, and (b) providing a clear indication of the wind direction (6.1, 8.5). [23]

20 A number of types of pilot information display have been reviewed with respect to their potential for assisting with the helideck environment issue. Such

[22] A study to define a permitted level of turbulence has been initiated by CAA and is now underway.

[23] A study, initiated by the CAA and HSE, is now underway to investigate the feasibility of visualising gas turbine plumes on offshore installations.

systems are under active consideration for naval helicopter use, but it was not possible to draw firm conclusions on their applicability to offshore operations (5.4).

21 The planned introduction of status lights on offshore installations should provide an immediate means of warning pilots of problems providing that the use and interpretation of the systems is unambiguous (8.5).

22 The status lights and/or warnings by radio are also the preferred method for warning pilots of the presence of a gas cloud. Consideration has been given to the installation of gas detection systems on the helicopter, but significant gas releases are likely to be much better detected by the existing systems on the platform (8.7.1).

23 Considerations of engine surge margins have indicated that a helicopter should be able to safely fly into a hydrocarbon gas cloud of up to 10% Lower Flammable Limit (5.3.3). [24]

24 The origins of the vertical gust and temperature criteria which were lodged in CAP 437 some 17 years ago cannot be traced, and this has tended to undermine their credibility. However, experience has tended to indicate that they are based on sound engineering judgement. Some of the shortcomings that have been identified are (6.2, 8.6):

- Wind flow studies on offshore platforms have shown that full compliance with the 0.9m/s vertical wind speed criterion is seldom possible (6.3).
- The 2°C temperature rise criterion fails to recognise the time dependence of the temperature changes experienced in a hot plume (6.4.2) [25].
- No guidance is given on the vertical clearance that should be allowed when a hot plume traverses a helideck (6.4.2). [26]
- No quantitative criterion is given for levels of turbulence which would be a useful addition to the design criteria (8.7.2). [27]

25 Helideck design has to-date been largely a matter of simply satisfying the requirements of CAP 437 with little or no consideration being given to the operational capability of the deck (8.1).

26 There has been a lack of feedback from helicopter operators to helideck designers (3.5, 8.1).

27 The need for a comprehensive helideck design guide has been identified and would go a long way to solve many of the issues identified here. Such a guide

[24] The Third Edition of CAP 437 (October 1998), issued during the course of this project, now specifies 10% Lower Flammable Limit.

[25] In the Third Edition of CAP 437 (October 1998), released during the course of this project, the averaging period for the 2°C temperature rise is specified as 3 seconds.

[26] The Third Edition of CAP 437 (October 1998) now specifies that the height above the helideck to be considered should take into account the airspace required to accommodate helicopter take off and landing decision points.

[27] A study to define a permitted level of turbulence has been initiated by CAA and is now underway.

would obviously need to command the respect of helicopter operators and helideck designers (3.5, 8.8).

28 Helicopter operations offshore are subject to regulation by both the Civil Aviation Authority (CAA) and the Health & Safety Executive (HSE). The CAA Safety Regulation Group is responsible for regulating the airworthiness and operational safety of aircraft including its passengers. The HSE is responsible for regulating the safety of offshore workers. The offshore installation owners and duty holders are responsible for the safety of the entire installation including the helideck and helideck operations (7.1).

29 The Offshore Installations (Safety Case) Regulations 1992 require installation owners and duty holders to identify all hazards which could cause a major accident, and to take measures to reduce the risks. It has been noted that, in the past, guidance on the application of the Safety Case Regulations has been focused on the risk to the installation from an impact from the helicopter, and has not explicitly encompassed the hazard the installation poses to the helicopter (7.2).

30 There are a number of ways in which actions of the duty holder, if not properly controlled, could prove to be prejudicial to the safety of the helicopter. These include for example; any activity which adversely affects wind flow over the helideck, combined operations involving a flotel or other structure in close proximity, and releases of hydrocarbon gas (7.2).

10 RECOMMENDATIONS

A number of recommendations have been made arising from the conclusions drawn in the previous section. Following the approach advocated by the CAA in the original proposal, a series of actions have been recommended under three headings. Most of the actions can be started immediately, but some will take effect and show benefits in the short-term, whilst others will take longer to bear fruit. As with the conclusions, numbers in brackets indicate the sections in this report where explanation and justification for the recommendation may be found.

10.1 Short-Term Benefit Actions:

It is recommended that the following actions be taken to improve the quality and applicability of the environmental requirements currently contained in CAP 437. The actions should be completed and the benefits felt within the short term.

(i) Relate current and future environmental criteria to the hover/thrust margin (or its equivalent) available for recovery, as the basis for future hazard assessment (8.4).

(ii) Determine the limits on hover/thrust margin currently available to pilots operating to offshore installations (8.4, 8.7.1).

(iii) Reaffirm the current limit on vertical wind speed of ±0.9 m/s. This can be linked with approximately a 3% hover/thrust margin to achieve recovery (5.1.4, 8.4).

(iv) Reaffirm the current threshold for ambient temperature rise as 2°C. This can be linked with approximately a 0.4% hover/thrust margin to achieve recovery (5.1.6, 5.3, 8.4, 8.7.1).

(v) Specify the 2°C ambient temperature criterion as that occurring over a 3-second time interval[28], at and below a height above the helideck corresponding to 30 ft plus wheels-to-rotor height plus one rotor diameter. The height of 30 ft is taken to be sufficient to include the requirements of both the take-off Rotation Point and the landing Committal Point (3.3.3, 3.3.4, 4.1.4, 5.1, 8.4). [29]

(vi) Review the long-standing recommendation in CAP 437 that visible smoke be emitted from gas turbine exhaust outlets during helicopter operations, to determine why there has been a reluctance on the part of platform operators to act (6.1, 8.5)[30].

(vii) Establish a provisional limit for the maximum permitted level of turbulence by comparison of pilot experience, as represented in the IVLL records for example,

[28] The Third Edition of CAP 437 (October 1998), issued during the course of this project, now specifies that the averaging period for the 2°C temperature rise criterion should be 3 seconds.

[29] The Third Edition of CAP 437 now specifies that the height above the helideck to be considered should take into account the airspace required to accommodate helicopter take off and landing decision points.

[30] A study, initiated by the CAA and HSE, is now underway to investigate the feasibility of visualising gas turbine plumes on offshore installations.

with the data obtained from the corresponding wind-flow studies where such data is available (8.1, 8.7.2).

(viii) In view of the fact that it is not considered to be practical to detect hydrocarbon gas concentration over the helideck, or on the helicopter flight path, ensure that existing platform gas leak detection and blowdown systems are linked to helideck status lights, and procedures are in place to ensure that helicopters are immediately warned to keep away in such situations where a hydrocarbon gas cloud might be present. It is recommended that CAA consider amending CAP 437 accordingly [31] (5.3.3, 5.4.6, 8.5, 8.7.1).

10.2 **Medium-Term Benefit Actions:**

It is recommended that the following actions be taken to strengthen and improve relations between the helideck designers, the regulators and the helicopter operators. The actions should be set in train immediately and should yield benefits in the medium term.

(i) Establish a scientific basis for a limit on the permitted level of turbulence by means of a study of helicopter response in the offshore turbulence environment (6.4.1, 8.4, 8.6)[32].

(ii) If and when available, exploit the routine monitoring of FDR records as a means of obtaining continuous quantitative feedback on the impact of environmental factors on the safety of helicopter operations (2.4, 3.2.2, 8.1, 8.2).

(iii) Commission a wind-flow modelling study of the Claymore Accommodation Platform incident both to determine the cause of the problem and to establish the environmental conditions prevailing at the time (1.1, 2.2, 3.4.2, 8.1)[33].

(iv) Establish a methodology whereby the results of wind-flow modelling studies can be made available to helicopter operators in a standard and meaningful format. This could take the form of operational envelopes similar to the SHOLs used in naval helicopter operations. Platform designers should include the production of these standard envelopes as part of the contract and scope of work for the wind-tunnel testing of their designs. The definition of an 'environmental hazard zone' may be helpful (3.2.2, 8.7.1).

(v) Support moves to combine the IVLL, operational envelopes and Aerad information into a single presentation, possibly in the form of a PC-based database. This would provide the pilot with up-to-date information on the location of potential environmental hazards in the current weather conditions. It might also include a facility for advising a pilot of the most appropriate approach and take-off strategies for a given set of environmental conditions (3.2.3, 8.5, 8.9).

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[31] The Third Edition of CAP 437 (October 1998), issued during the course of this project, now specifies 10% Lower Flammable Limit.

[32] A study to define a permitted level of turbulence has been initiated by CAA and is now underway.

[33] A study into the Claymore accident has been initiated by CAA and HSE and is now underway.

(vi) Review procedures currently used on offshore installations for reporting of current weather conditions to pilots with a view to achieving a higher and more consistent standard (3.2.1, 4.1.2, 8.5).

10.3 **Longer-Term Benefit Actions:**

It is recommended that the following longer-term actions be taken to further the development of the underlying design and safety issues affecting helicopter operations to offshore installations:-

(i) HSE and CAA should encourage the publication by industry of a Design Guide for offshore helidecks to run in parallel with CAP 437. It is recommended that the preparation of such a Guide be handled as a Joint Industry Project with the participation of the offshore design and construction industry, the helicopter operators and the regulators (2.8, 3.5, 6.1, 8.1, 8.6, 8.7, 8.8).

(ii) Industry's attention should be drawn to:

- The need to resolve the present deficiency of lack of suitable and sufficient operational information being provided to helicopter operators for flight planning purposes. There is a pressing need to improve the quality of the information being provided to flight crews about the potential for, and the probable extent of, adverse environmental conditions on and around installations. Offshore safety requires co-operation between everyone who has a contribution to make to ensure health and safety on an offshore installation or the activities involving the installation. The scope of Regulation 8 of MAR [32] is, therefore, very wide and includes operators, owners, concession owners, employers, employees, managers and people in charge of visiting vessels or aircraft (4.1.7, 4.3.1, 8.9, 8.10).

- The need for Design and Operations Safety Cases to adequately address the probable effects on helicopter flight operations caused by adverse operating environments created on and around offshore installations. These adverse effects result mainly from production processes and structures on the installation or from adjacent installations and vessels. When combined with ambient weather conditions the resultant effects can place helicopters in jeopardy, particularly during critical flight phases (7.2, 8.9, 8.10).

(iii) Duty Holders should ensure that within the offshore installation Safety Management System helicopter operations must be adequately covered. Key features should include:

- A comprehensive schedule of all those factors affecting design and operation of the installation that are likely to be prejudicial to the safety of helicopter operations. Examples of what might be included are given in Section 8.10.

- Standards to be attained and procedures to be used for monitoring and control of installation activities to ensure an acceptable level of safety for helicopter operations is maintained (4.1.7, 4.3.1, 8.10).

- Procedures for communicating relevant information to helicopter operators in a timely manner, including any departure from agreed operational practice which may have an adverse effect on helicopter safety (3.5, 4.1.7, 8.10).

(iv) HSE should consider amending the Assessment Principles for Offshore Safety Cases to explicitly include the hazards and risks to a helicopter and its passengers from the installation and its processes.

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Annex 1

EXTRACT FROM CAP 437 (1993) REFERENCE [9]

3 AIR TURBULENCE AND TEMPERATURE GRADIENT

3.1 Turbulent airflows across the landing area can be caused by wind flow around adjacent structures and by prime mover exhausts (in particular gas turbines), which can also cause temperature gradients. These effects can seriously influence helicopter handling or performance characteristics.

3.2 Landing areas situated directly on top of deep slab-sided structures such as accommodation modules, have been known to suffer from excess vertical airflow components unless there is sufficient separation to allow airflow beneath the helideck.

3.3 For this reason the combined effects of airflow direction and turbulence, prevailing wind and installation prime mover exhaust emissions, should be determined for each installation. Further information on these matters can be found in Davies et al 1977 and 1979, and Davies 1979 (see Appendix B, ref 1). Suitable wind tunnel model tests should be carried out to confirm the suitability of the arrangements. The resulting information should be made available to the helicopter operator and the Civil Aviation Authority. As a general rule, the vertical component of airflows resulting from wind velocities up to 25 metres per second should not exceed +/-0.9 metres per second over the landing area at main rotor height.

3.4 Ideally, where gas turbines are installed and the exhaust gases may affect helicopter operations, some form of exhaust plume indication should be provided for use during helicopter operations, for example, by the production of coloured smoke. Unless it is obvious that the air temperature in the vicinity of the flight paths to and from the helideck will not be affected by the exhaust plume, a survey of ambient temperatures should be conducted during periods when the wind is blowing directly past the turbine exhaust duct towards the landing area. Where the ambient temperature, in the vicinity of the flight paths and over the landing area, is increased by more than 2°C the helicopter operator and the Civil Aviation Authority should be informed. If required further advice on these aspects may be obtained from the Civil Aviation Authority (Aerodrome Standards Department).

Annex 2

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Annex 3

SUMMARIES OF HELIDECK RISK STUDY AND PILOT WORKLOAD SURVEY

1 A Study of Helideck Risks – National Air Traffic Services Report CS 9455.

A study of helideck risks was performed by the Chief Scientist's Division of National Air Traffic Services on behalf of the UK Health and Safety Executive in the early 1990's. The objective of the study was to provide information to help the CAA and its funding partners to prioritise research in the area of offshore helidecks.

The following passages have been extracted from the summary of the discussions with industry specialists that formed a major part of the study:–

2.2 ***Helideck Aspects***

2.2.1 ***Aerodynamics***

HSE design approval includes the rig aerodynamics. The aerodynamics of the whole rig as a working environment are considered, for example gas concentrations around accommodation areas, not just the helideck aspects. The latter are now believed to be largely understood, and the design of most new decks is considered by some specialists to reflect this (this view is not shared by some pilots, as noted above). Knowledge of the flow through and around rigs has been obtained by wind-tunnel testing, initially by studying the flow around existing rigs with aerodynamic problems, mostly by OES (Offshore Environmental Services, Cranfield) and BMT (British Maritime Technology, Teddington), although wind tunnels in France and Norway have also been used. Few full scale measurements have been made. OES carried out an aerodynamic survey of existing rigs in 1987, funded by CAA. Tunnel testing is now carried out as part of the initial design clearance, with CAA acting as advisors on certain aspects. The vast majority of platforms now operating in the North Sea have been tested at the design stage, about 50% of this work having been carried out at BMT. Recommended procedures for dealing with the effects of the aerodynamics of individual rigs are given in the helicopter Operations Manuals. In-service modifications to the oil platform upper structure are usually considered unlikely to have a significant effect on the platform aerodynamic (this view is not universal) and are not usually tested. An exception is the Brent Bravo platform where major alterations are currently being proposed. There is no formal procedure for clearing such aerodynamic effects, or for deciding whether this is needed.

Aerodynamic factors consist of steady flow deflections, turbulence, and temperature gradients, caused in varying degrees by the following:

Deck position and support *– In order to create a safe flying environment without any excessive regions of vertical flow it is important that the helideck is positioned high relative to the rest of the upper structure, and that a horizontal air gap is maintained between it and the structure below. It has been found that an air gap of between 3m and 5m is sufficient for a high percentage of all likely wind conditions. There have in the past been problems with the air gap being compromised by use as storage space – it is the responsibility of the HLO*

(Helicopter Landing Officer) to ensure that this does not happen. Improvements complementing the air gap have been flow turning vanes situated around the perimeter of the helideck such as on the Hutton platform. On the Forties Charlie platform the helideck was positioned low compared with the main superstructure, and thus situated in a separated down flow. This leads to a 'cork from a bottle' effect on take-off, whereby, as the helicopter flies through the separated shear layer and into clear air the required power suddenly falls causing a sharp acceleration. Of greater concern is the converse situation where a sudden increase in power is required in the final stages of a landing.

Derrick structure *– ideally this is open but it is often clad for rig crew comfort, when it has a bluff body effect (upstream flow deflections and separated wakes) on the flow.*

Gas turbine efflux *– this can be serious when pumping oil/gas; the power of two industrial Rolls Royce RB 211s is typical, with total exhaust flows of up to 180kg, or 140 cubic metres, per second. CAP 437 recommends the use of coloured dye to mark the position of hot gas plumes, but this technique is not used in North Sea operations; the practical problems of correlating the diffusion of the dye with density and temperature gradients, and decreasing the visibility in the immediate vicinity of the helideck, would be of significant concern.*

Flying into hot plumes can cause blade stalling or a general decrease in performance at a particularly demanding phase of the flight i.e. approaching the hover where power requirements are high and rising. In practice temperature fluctuations are large but fast, therefore engine surge rather than loss of rotor lift is the main problem. The helicopter rotor will pull a plume towards it if nearer than rotor radius. An improved understanding of the problem is gained by modelling the development of gas plumes, either in the wind tunnel by using density to replicate the effects of elevated temperature, or by computational methods. By this means the gas turbine stacks and flares may be positioned so that under most wind conditions their effect on the helicopter flight path is minimal, or at the very least the effects are evaluated so that the appropriate operational restrictions can be specified. Increasing wind conditions can lessen the effects, as the plumes dissipate more rapidly.

Gas flare *– These may or may not be lit, and can be a particular problem if unscheduled. The flare stack can be in alternative positions. The radiant heat from a lit flare can be considerable. The helicopter crew must be advised if the temperature rise on the flight path or at the deck exceeds 2 deg C, from flare and/or efflux effects. The deck anemometer can also be affected by a flare stack.*

Vessels alongside *– Although most of the time the current regulations are probably sufficient to provide safe operation to helidecks, on occasion (usually during the construction or modification of a platform) a jack-up platform or flotel may be moored alongside the main platform. These can have a major effect on the overall rig airflows including those at the helideck, but due to the variety of possibilities are not tunnel tested. These service platforms also often have their own helidecks which would not have been tested in this environment, and hence the effect on safety not evaluated.*

The certification requirements for rig aerodynamics as specified in CAP 437 are rather basic and BMT, for instance, apply further criteria (developed from their *own experience) which CAA find acceptable. As well as being ambiguous and vague in places the current certification requirements relate only to uniform vertical velocities, whereas gradients of vertical and horizontal velocity can have a large impact on the helicopter response and pilot workload. It should also be noted that comprehensive testing would involve some 'pilot-in-the-loop' simulation in order to evaluate fully the interactions between the turbulence field, the helicopter dynamics and the pilots' response. However, this is not necessary to satisfy current requirements. There is some pilot mistrust of turbulence predictions from wind-tunnel testing of rigs.*

There is a proposal by CAA to use the DRA (Malvern) laser Doppler anemometer, to study the full-scale flow around a rig known to feature flow disturbances troublesome to helicopter operations, possibly in 1993. Neither rig nor aircraft has yet been chosen. It is hoped to ascertain the aircraft and pilot response to varying levels of turbulence, vertical as well as horizontal. Large commercial helicopters now have comprehensive data recording for crash recorders, which could possibly be used, although there is some doubt on the adequacy of data rates for the envisaged research. The WHL HAPS (Westland Helicopters Limited, Helicopter Airfield Performance Simulation) helicopter dynamics package would be used.

BMT have done some work in the past to calibrate wind velocity and temperature sensors so that a correct reading of the conditions at the helideck can be obtained. They do not consider this to be an area of any concern.

BMT have also done research for the prediction of the disturbed flow off the back of Navy frigates. This has lead to the development of a spatial and temporal turbulence model which, it is hoped, can be fed into a helicopter simulator with the 'pilot-in-the-loop' in order to evaluate the optimum approach and departure from such a helipad, under various conditions of turbulence severity. The model has yet to be implemented due to a lack of funding but could also be applied to simulations of the approach and departure to helidecks in the North Sea.

2 A Questionnaire Survey of Workload and Safety Hazards Associated With North Sea and Irish Sea Helicopter Operations – CAA Paper 97009.

A questionnaire-based survey of all offshore helicopter pilots was performed by the DERA Centre for Human Sciences on behalf of CAA in the mid-1990's in connection with a study of the workload associated with the completion of paperwork in flight. The analysis of the results was published in CAA Paper 97009 in August 1997. An unprecedented response rate of 73% was obtained, indicating that the conclusions drawn from the results could reliably be considered representative of the offshore pilot population.

In order to attempt to camouflage the true intent of the questionnaire, and thus avoid bias in the responses, the questionnaire addressed a broad range of offshore issues including turbulence, for which the following question was included:-

'Does Turbulence around the platforms cause you a high workload or a safety hazard?'

Respondents were requested to indicate their response on a scale of 1 to 10, where 1 ≡ never and 10 ≡ always. For high workload, the mean response was 6.4 with a standard deviation of 2.0; for safety hazard the mean response was 5.9 with a standard deviation of 2.5. Overall, turbulence was found to contribute to high workload and safety hazards more frequently than any other aspect of offshore operations.

Respondents were also invited to submit 'freeform' comments on a number of the questions, including the above question regarding turbulence. 51% of respondents provided comments relating to turbulence which are reproduced below:-

1 Experience tends to negate the problems with turbulence as tight limits are set as regards wind speed/direction on various platforms, rigs etc. Can still get caught out occasionally but I've never been concerned.

2 Safety is kept up by reducing our aircraft weight in order to have power in hand.

3 South winds in Brent A,B,C,D, Cormorant A 25 kts+ north winds North Cormorant, Eider, Tern etc. Spectacular siting of turbine exhausts (Term), crane (Eider) and computer design of North Cormorant (limited to 25kts for close for example) – who designed these!!

4 Obviously depends on wind direction – can be very uncomfortable.

5 You can usually predict when turbulence will be present, but not the severity. A simple smoke generator or flare released as the crew carry out a fly-by would show the pilot any dangerous down-draughts or wind reversals when necessary.

6 These operations are never completely safe as had been shown by various incidents, but the risks are kept low in restricting flight in certain weather conditions. In my view, winds of over 50 – 60 kts on decks should cause the deck to be closed. (except in emergency!).

7 Sometimes, dependant on wind strength and direction. The greater the workload the greater the hazard.

8 Some turbulence can be particularly bad on certain platforms. Most platforms create turbulence when the wind comes through the cranes or derricks.

9 When in turbulent arcs.

10 Cloud demisters should be outlawed! (I probably wouldn't say that if I was a roustabout). The Brae platforms are appalling with some wind directions and there should be a revision of thought regarding public transport operation to them in such winds.

11 Depends very much on circumstances. Current regulations restricting certain rigs have improved matters. Due to the infinite number of variations of wind velocity, even a single rig's conditions can vary widely. Turbine exhaust has a severely detrimental effect. Rules and limits are almost impossible to formulate to cover every eventuality – experience and caution are required.

12 The installation/vessel limitation list as promulgated by the BHAB sub committee has a bolt on section giving turbulence information, provided this information is kept up to date by pilot, voyage or M.O.R. reports, the surprises of the past of having to abort landings in cases of high turbulence, nil airspeed. High power settings, should be a thing of the past, however, not all the information can be 100% correct all the time, someone sometime is the guinea pig hence 10 scores.

13 Not very often down hill. Need to consider, though.

14 Wind through the superstructure on approach does cause considerable turbulence giving a 'windshear' or downdraught effect very often. Both take-off and landing power can be much higher than normally required.

15 The hazards associated with mobile rigs are well documented. However, too rigid a statement of limits (as we have) could lead the unwary towards thinking than an approach just within limits is perfectly safe. Nothing is perfectly safe. Such limits can also be used a s a stick to beat us with if we throw away an approach and incur extra costs for the company.

16 High workload – occassionally. Safety – rarely, reduced by experience and general awareness.

17 The unpredictable nature of turbulence is the cause of these high scores, and turbulence is often just as dangerous with 10–15 kts wind which can be suddenly lost/turned into a downwind component with consequent power requirement beyond that available – over-torque incidents just on take-off or landing have (and will continue to) happened.

18 The most severe turbulence is encountered when landing on drilling rigs with the helideck downwind of the drilling derrick. This causes strong eddies which in the worst case produce almost a complete reversal in the airflow direction at the most critical stage of an approach, i.e. at low forward speeds and high power settings with the aircraft close to the helideck.

19 Sometimes with a clad derrick etc.

20 Certain rigs well known for turbulence.

21 In certain wind directions the aircraft can be very different to handle often requiring large amount of power to arrest descent. Turbine exhausts and clad derricks are the worst.

22 The 'turbulent sector' of some landing areas can be the most stressful few seconds of my life – any aspect of my life.

23 Although turbulence sectors are published there can still be 'interesting' landings.

24 When the wind direction causes turbine exhaust turbulence during an approach the answer to 47 is categorised as 8 for both.

25 This is almost/perhaps the most critical and stressful part of a flight to an offshore location, when the wind direction is reported in the promulgated turbulent sector for a given deck. Quite frankly, it can be frightening and more so when the other pilot must do the landing. One such landing can double the overall exhaustion level for that flight.

26 Depends on wind direction, turbine exhaust.

27 The worst case is strong winds blowing through a drilling rig onto the helideck. When landing at near maximum all up weight this can be tricky and requires a steep approach, otherwise there is a possibility of over-torquing to prevent a rapid rate of descent developing. I cannot see any cure for this other than reducing the all up weight of the aircraft, which is already done in severe cases.

28 This is manageable provided you are aware of potential turbulence prior to the approach (appropriate weight reductions can be made). Its the unexpected that has caused problems in the past.

29 Poor planning of deck position relative to obstructions and heat sources such as flames or turbine exhausts. A series of platforms in one area often share the same problems of design, and platform orientation.

30 Only on particular platforms in certain winds – problem well addressed by new vessel operating limit sheets.

31 Generally no, but when the wind is in or near the 'turbulence sector' for a rig, or the wind is at or near the windspeed limits for a rig, workload/hazard is high. Often the worst turbulence can be found after the landing committal point.

32 The Brae 'A' helideck is dangerous in northerly winds!! Although there are limits, an engine failure during takeoff or landing would have catastrophic results!!

33 Clad drilling derricks seem to cause a lot of turbulence even when landing/taking off in accordance with the I.V.L.L.

34 If this refers to strong wind situation through a mast or turbine structure then there is a case history of a safety hazard, not all decks have enough restrictions, some have slipped through the net.

35 Again poor question – if it is turbulent I have to work harder – surely this is obvious.

36 With the wind through the derricks there will always be turbulence. The new IVLL limits are about right.

37 Turbulence is uncomfortable and unsafe. Some platforms (such as the Brae 'A') have you flying with fingers crossed all the way in when the approach is in the turbulent sector. On this particular platform (and there are others) you 'commit' to the deck a long way out, and your overshoot for quite a wide arc is all steel.

38 We do identify turbulent sectors which are published so all are aware but workload is undoubtedly increased with associated increase in safety hazard.

39 Again, depends on aspect. Semi-subs with clad derricks, or flotels alongside production platforms, tend to be by far the worst. The IVLL sector data has got rid of most of the problems but there are still cases with the wind notionally outside the danger sector or at a lower speed where problems arise. Additionally, flotels' anemometers are subject to screening or shielding by the platform which gives a false reading.

40 Turbulence causing loss of lift occurs as follows:–

(1) Flt. deck downwind of turbine exhaust plumes when wind 10 to 20 kts.
(2) Flt deck downwind of and below accommodation blocks in strong winds. Rotor induced flow is increased – lift is lost.
(3) In light winds, on production platforms continuously flaring and thus causing air to rise and thus colder air moves horizontally towards the platform whichever direction the helicopter approaches from, it is downwind.

41 It is always wind direction/speed dependent, landing on the Brae A in a fresh northerly wind is very exciting!! but with a westerly or southerly – no threat.

42 To the platforms to which I fly turbulence is a very occasional problem.

43 Some recent platforms particularly turbulent with wind in certain directions.

44 Why do platform designers continue to put turbine exhausts alongside the helideck and usually just at the right height to cause maximum turbulence. Example: Ninian Central with a southerly wind.

45 We have well researched and presented information and guidelines on this front. The worst of the platforms we visit are the Brae. We are aware of when problems are likely to occur.

46 Landing on a flotilla in the lee of a fixed platform we can calculate our landing weight using unrestricted graph with full wind accountability. This is WRONG. Down draughting would sooner or later cause an over-torque or crash. I know of no one who uses it. The rules sometimes seem to be designed to hang you.

47 High workload only when wind is in turbulent sector when it is, it can be very hazardous.

48 Experience goes a long way to help by knowing conditions that cause turbulence on each individual platform.

49 Unexpected excessive turbulence can cause problems, sudden flare, gusts etc. Wind shadow and reversal across deck is common resulting in tail wind/high power as coming to hover.

50 Someone will be thrown onto a deck/into a structure – and it will be caused by turbulence and blamed of course on pilot error. They are correcting this problem by giving us a better margin but it is surprising how often the wind velocity is within 1 degree or 1 knot of our limits – closer supervision perhaps. Pity you do not get to hear about all the 'guess what almost happened to us' stories – I sometimes think we have got 'used' to the turbulence too much.

51 Variations from platform to platform under varying wind conditions. Known problems are reported and suitable restrictions applied.

52 Bad design of older rigs, platforms, e.g. Brae ‘A’, Buchan ‘A’.

53 I do not go to barges in the Lee of platforms i.e. wind blowing through platforms anymore. Captain’s desecration. Make alternative arrangements.

54 Can usually be seen in daylight and is therefore easier to avoid than at night when due to exhaust – otherwise local knowledge applies.

55 If its bad then the flying is very difficult and the aircraft gets some rough treatment and safety is compromised.

56 Depends largely on platform design, also proximity of other structures. Turbulence often caused by turbine outlets or poor siting of helideck on structure.

57 Answers refer to the occasions when we experience turbulence. Turbulence is so unpredictable. Platform design could help but even newer platforms like Tern and Eider have appalling turbulence problems. Helicopter operational problems seem to hardly be considered by platform designs, or by rig operators when laying anchors. Why for example is the Santa Fe 140 helideck currently to the NNE of a clad derrick? With prevailing SW wind, we often have turbulence problems on this rig.

58 The Brae A & B are renowned for this, on the rig giving 30kts of wind when others are in the 50kts region and the anemometer/wind sock is down wind of the derrick housing.

59 Obviously only in high wind speeds.

60 Self imposed turbulence limits seem to work well.

61 One is always aware of the possibility of turbulence and hopefully this prevents it from becoming a greater safety hazard. However, we are taken by surprise sometimes.

62 In my opinion the most hazardous part of our offshore operation is landing on floating decks in lee of platforms at night.

63 This depends on the particular platform and the wind direction. The worst platform I have experienced is the Brae ‘A’ and can be 10 for both workload and safety. With other wind directions it can fall to 1. The Beatrice ‘A’ on the other hand is virtually always 1 for both scales.

64 This is a difficult question because it all depends on the level of turbulence. On some rigs/platforms it is a serious safety hazard and requires care and experience to judge the difficulty.

65 When wind is just outside the restricted arc or just below the limit on some rigs/platforms, it can get a little bit uncomfortable.

66 If wind is blowing through turbulent sector handling becomes difficult and with limited power available it is always on the back of our mind the possibility of over-torque just trying to maintain adequate control.

67 Generally platforms/rigs acceptable in the southern North Sea.

68 Depends – high winds are a fact of life on the North Sea. turbulence will always be with us. Awareness and training are the key.

69 Part of life on the North Sea I guess, though helideck location does help a lot, as does location of turbine exhaust and flare stacks. Something I guess designers should be more aware.

70 Exhaust of turbines should be placed to give minimal disturbance to the helicopter.

71 Applicable mainly to turbine exhaust on certain production platforms.

72 There are guidelines for example, the IVLL, but ultimately it is one's knowledge of the rig and aircraft which is crucial.

73 When there is severe turbulence it is not uncommon to go-around and subsequently operate to a different deck or return to base. The knowledge of certain decks is improving, but certain fields insist on the same orientation of decks, turbines, flares, derricks etc.(items that cause turbulence) on new platforms (i.e. if you can't land on one, you can't land on the rest.

74 Turbulence is partly planning. I and my 'old' colleagues flew S58T's and S61N's into decks in the early days and compensated for the poor power response of these aircraft by planning our approach carefully. People generally got into trouble because of a poor approach and 'aggressive' handling. (this is a personal viewpoint!).

75 It can be downright dangerous but it is unusual for the experienced to get caught.

76 Platforms displaying very different characteristics. Some have almost no turbulence, regardless of wind speed/direction., others (e.g. Brae A in strong north wind) require an early committal into untested turbulence. Take-off's even worse, especially at night.

77 On certain platforms/rigs depending on wind velocity, and turbine efflux.

78 The decks on new platforms seem to have been designed to meet the minimum theoretical minima. They do not project over the side and often one's nose is almost over the edge of the deck when on the 'Bum Line' making landing at night potentially hazardous. Compared with the Brent decks, the newer ones are more like the Forties decks before they were modified, close in to the centre of the platform and nearer obstructions. A retro grade step (after 17 years, maybe I'm cynical, but could it have something to do with money).

79 New, smaller decks closer to centre of platforms have increased turbulence problems. e.g. Piper B, has covered stairwell projecting above deck level;

turbine exhausts and structure directly adjacent to deck. I'm led to believe that whilst wind tunnel tests were carried out, they did not simulate turbine exhaust. However, one cannot simulate common sense!

80 There are some structures both platform and rigs that can be dangerous in certain winds. Turbulence at a strange rig at night is no fun.

81 Some approaches, although the wind speed/direction within limits are precarious.

82 Floaters next to platforms frequently cause the S61 problems, when wind direction is through the platform.

83 Can be a real problem especially with semi-sub flotels in the lee of platforms. Down draughting is a severe problem. The combination of downdraughting, reverse wind flow, pitch, roll, and heave can make things very difficult. We tread a fine line here, very easy to damage an aircraft on landing. I believe that our limitations do not take proper account of these factors. Only our experience and judgement keeps us out of trouble.

84 In the turbulent sector on some rigs the workload is always high and the safety hazard will be there as well. Question is therefore unanswerable.

85 When landing and taking off in the turbulent sector, some rigs (very few) have ducted turbine exhausts that take the exhaust completely away (excellent), where most build the exhaust stacks next to the helideck (confusing).

86 Even a powerful A/C such as the super Puma can be difficult to control in severe turbulence.

87 Some decks are very turbulent on the approach and a reduced AUW has to be used.

88 The turbulence around the smaller platforms in the southern North Sea is not usually a problem. However the legs and superstructures on jack-ups does sometimes give problems.

89 Depends on the day, depends on the wind. Some rigs ok, some are pretty bad. I'd love to meet the guy who designed some of these helidecks.

90 If turbulence is present, you will have a high workload, and often be running out of power on takeoff and sometimes landing.

91 Can be very exciting – local knowledge is vital here – would like to be involved with take-off certification pilots when a new machine enters service.

92 Turbulence is generally not a problem.

93 If the deck is down-wind of structures/flare/turbine exhaust – so called turbulence sector approaches.

94 In the Puma with 2 engines working its ok with existing limits. At night, high turbulence with single engine failure there is a significant risk.

95 Local knowledge is the key; if areas of turbulence are known landing weights can be adjusted.

96 With winds of 30 kts plus blowing through, around, over the structure even at the reduced weights we may be operating at for turbulence, the safety hazard is high. Should a power unit fail during take-off or short finals the consequences are likely to be disastrous. We do not operate to group A standards offshore.

97 Clad derricks/turbine exhausts from upwind require extreme caution and could be hazardous.

98 One often wonders who allowed the turbines/flares/clad derricks and other obstructions to be placed in positions adjacent to the helideck.

99 This is most likely cause of all offshore landing stresses. But only on certain platforms.

100 All turbulent sectors have limitations which has withdrawn this problem.

101 Be aware!

102 Rarely causes a hazard if limitations are observed.

103 This is particularly so when using flotels connected to fixed platforms. Increasingly, pressure appears to be being applied to use these decks to save time and improve efficiency. We tend to ignore these pressures in the name of flight safety and use the fixed platform deck!!!

104 This is improved with the introduction of the IVLL but this in turn has increased workload as it has to be referred to both before flight, monitored in flight or if a change of routing occurs it is another action that has to be taken. New procedure = more workload.

105 We are restricted in take-off weights when the wind is below 10 kts or the helideck is shielded from the wind depending on direction through the structure – this is usually in turbulent conditions also – causing an increase in workload due to recalculations. I have never understood why all rigs in an area don't have all their helidecks facing the same way (and the most convenient direction for a landing helicopter).

106 Very much depends on individual rig design/wind velocity. Brae 'A' – the pits!

107 Dependent on direction and particularly if drilling derrick is fully clad e.g. Santa Fe 135 is dangerous at times!

108 Into the unknown at times. Simply because turbulence cannot be seen even if it is expected. I have on one occasion been out of control – fortunately finding the effect diminishing as deck height reached. The incident was put forward as an M.O.R. The company issuing expanded limits.

109 Strong winds make landings and take-offs a major hazard at times.

110 This is specific to wind direction and strength i.e. where the deck is in the lee of the derrick or structure. This has been adequately dealt with by the restrictions applied.

111 Doesn't seem to be much of a problem in the southern North Sea.

112 Semi-subs in the lee of platforms and clad derricks are very demanding.

113 Performance 'unknowns' may be a hazard.

114 Go-arounds sometimes occur due to turbulence. But sometimes the turbulence is not evident until 'committed'. You get to know which rigs give the problem e.g. shrouded drill derricks with wind 'through' them.

115 Known problem for example on Forties when wind in turbulent sector. Poor initial design with known prevailing winds.

116 There are a few platforms which I consider would be dangerous in certain wind directions, if an engine failed in the latter part of an approach.

117 Particularly at high wind speeds and operating at or near restricted landing weights to attached accommodation vessels.

118 Some are as bad as wake turbulence – there is a list of hazardous sectors for rigs which is continuously updated but sometimes turbulence cannot be anticipated.

119 Turbulent sectors in most wind conditions (light to strong) create difficult handling and are very demanding. The wind does not always respect the strictly demarked turbulent zones and unless a cautious approach is made can lead to difficulties at high all-up weight.

120 When turbulence exists the workload inevitably increases. Occasionally, without an increase in workload, the safety is reduced disproportionately by loss of lift caused by down drafting.

121 Especially flotels in the lee of platforms, a down draft can be a real problem.

122 Wind velocity at boundary of turbulent sector can be tricky – although technically within limits.

123 A few installations suffer from unacceptable turbulence in certain winds – greater operating restrictions should apply.

124 The avoidance of turbulence on the flight path and/or the existence of turbulence will naturally cause a higher workload and will add to the hazard factor.

125 Turbulence is one of the factors foremost in the mind when landing in strong winds.

126 Dependent on local knowledge and wind direction.

127 Weight restrictions appear to be adequate for the Puma. On rare occasions rig take-offs in the turbulent sector are such that loss of an engine would be a marked safety hazard.

128 You know your difficult sectors so make allowances on flight paths – Standing Orders restrict rigs/flotels in certain wind conditions pertinent to sectors of approach.

129 Not a problem at this base yet, it is still under construction. Turbulence can be severe when turbine exhaust is blown over the helideck.

130 Some helidecks on rigs with enclosed derricks can be very difficult to land on/take off from in high winds.

131 Some decks are worse than others.

132 Obviously it is not always turbulent. However, certain rigs with a bad wind direction can catch the most wary of pilots.

133 Helideck restricted arcs etc. do not always cater for turbulence, which often seems to be a matter of local knowledge with particular rigs/captains.

134 Strong winds outside the 210 degree sector increase workload through turbulence.

135 Sometimes, even with the wind in limits (officially) the helicopter can sometimes be barely controllable for short periods of time. New rigs are just as bad with turbines exhausting over the deck and clad derricks close to the deck.

136 Position of flare stacks, turbine vents etc. contributes to turbulence and their location relative to the helideck contributes to the difficulty of approach and landing. Turbulence generated by the deck and below deck space is also an important factor increasing workload and degrading safety.

137 Dependent on the extent of the turbulence.

138 The limits applied to decks which are prone to turbulence are not exacting. Sometimes after warning pax of turbulence there is none or little. Other times we wish we had not started the approach. A ten second puff of smoke released from the upwind side of the rig would tell us a lot.

139 Turbulent sectors are well documented and thus expected.

140 Some decks are very bad when wind is in the turbulent sector, particularly the semi-subs with clad derricks. The turbines on the platforms often exacerbate the problem.

141 Clad derricks, helidecks below the surrounding structure and helidecks placed on the downwind (prevailing) side of platforms are a menace to flight safety.

142 Turbulence is a big problem!

143 There are wind strength restrictions in certain arcs of certain rigs but we do rely solely on the information passed by the rig as to the direction and strength of the prevailing wind and at times this could be vastly improved.

144 Not a safety hazard. Just higher workload. In the environment we fly it will happen.

145 Most fixed installations in southern sector are good – jack-ups poorly positioned to prevailing wind can cause problems.

Annex 4

DATABASE OF HELICOPTER INCIDENTS LINKED TO ENVIRONMENTAL CAUSES

Report No:	**62**
CAA SDD No:	7605628G
Year:	1976
Occurrence Type:	MOR
Aircraft Type:	Sikorsky S 61
Helideck ID:	Piper 'A'
Flight Phase:	Approach
Failure Category:	Installation Design
Primary Cause:	Flare/Burners
Secondary Cause:	Turbulence
Caused By:	Unacceptable level of hot gases and dirty cooling spray from flare being blown across helideck. Pilot elected to overshoot.
Comments:	Adverse wind direction causing excess turbulence. Overshoot and landing made on adjacent installation.

Report No:	**76**
CAA SDD No:	7800937E
Year:	1978
Occurrence Type:	Accident
Aircraft Type:	Eurocopter Bo 105
Helideck ID:	Forties 'C'
Flight Phase:	Landing
Failure Category:	A/C Ops
Primary Cause:	Pilot Error
Secondary Cause:	Turbulence
Caused By:	Aircraft caught in downdraught as it was landing. Before pilot reacted Tail Rotor struck and became entangled in perimeter safety net.
Comments:	Pilot was making 63rd landing of the day!

Report No:	**64**
CAA SDD No:	7801941J
Year:	1978
Occurrence Type:	MOR
Aircraft Type:	Sikorsky S 61
Helideck ID:	Piper 'A'
Flight Phase:	Approach
Failure Category:	Installation Design
Primary Cause:	Flare/Burners
Secondary Cause	Turbulence
Caused By:	2 approaches made requiring excess power demand. Turbulence on finals. Hot flare/GT gases over helideck.
Comments:	Wind drift moving hot air over helideck. T/O difficult after flare volume reduced.

Report No:	**66**
CAA SDD No:	8004297X
Year:	1980
Occurrence Type:	Accident
Aircraft Type:	Sikorsky S 61
Helideck ID:	Sedco 707
Flight Phase:	Landing
Failure Category:	A/C Ops
Primary Cause:	Pilot Error
Secondary Cause:	Turbulence
Caused By:	As pilot was manoeuvring A/C to land in strong winds, the tail rotor struck part of the rig structure (handrails) about 20 feet above the helideck. All T/R blades broken but no other damage incurred.
Comments:	Rig didn't comply with DEn guidance. CAA Notice to pilots re interpretation / use of Norge rig markings.

Report No:	**78**
CAA SDD No:	8200777B
Year:	1982
Occurrence Type:	Accident
Aircraft Type:	Sikorsky S 61
Helideck ID:	Thistle 'A'
Flight Phase:	Landing
Failure Category:	A/C Ops
Primary Cause:	Flare/Burners
Secondary Cause:	Pilot Error
Caused By:	As A/C approached helideck it developed an excessive rate of descent and struck perimeter safety net. Excess rate of descent at 20-30ft not arrested by full power. Incorrect zero wind approach!
Comments:	A/C 350 lbs over MAUW. A/C OAT read +16 deg after shutdown. Radiated heat from flare in light winds.

Report No:	**98**
CAA SDD No:	8401139D
Year:	1984
Occurrence Type:	Accident
Aircraft Type:	Bell 212
Helideck ID:	Brent ?
Flight Phase:	Landing
Failure Category:	A/C Ops
Primary Cause:	Pilot Error
Secondary Cause:	Turbulence
Caused By:	A sudden windshift just before touchdown caused A/C to land heavily on the helideck damaging the main skid and the underside of the tail boom.
Comments:	May have been caused by unknown turbulent effects from the structure catching out the pilot.

Report No:	**68**
CAA SDD No:	8504154H
Year:	1985
Occurrence Type:	Accident
Aircraft Type:	Sikorsky S 61
Helideck ID:	MCP-01
Flight Phase:	Take-off
Failure Category:	A/C Ops
Primary Cause:	Turbulence
Secondary Cause:	Pilot Error
Caused By:	During T/O the A/C was forced backwards by turbulence. The horizontal stabiliser struck a radio mast and was bent 45 deg. out of position. A/C re-landed.
Comments:	Helideck take-off techniques & crew procedures reviewed.

Report No:	**69**
CAA SDD No:	8803087C
Year:	1988
Occurrence Type:	MOR
Aircraft Type:	Eurocopter AS 332
Helideck ID:	Safe Felicia
Flight Phase:	Landing
Failure Category:	Installation Design
Primary Cause:	Turbulence
Secondary Cause:	N/A
Caused By:	Severe turbulence on final approach to Flotel helideck. Required large pitch changes for control.
Comments:	Operator imposed restrictions on operating in severe turbulence.

Report No:	**72**
CAA SDD No:	8902897X
Year:	1989
Occurrence Type:	MOR
Aircraft Type:	Sikorsky S 61
Helideck ID:	Not Known
Flight Phase:	Landing
Failure Category:	Installation Design
Primary Cause:	Pilot Error
Secondary Cause:	Turbulence
Caused By:	Lower than normal approach.T'wheel hit 6" raised deck edge. a/c bounced once into hover before landing.
Comments:	Turbulence from rig structure, windsock not conspicuous and A/C aft C of G all contributed.

Report No:	**73**
CAA SDD No:	9100572H
Year:	1991
Occurrence Type:	MOR
Aircraft Type:	Eurocopter AS 332
Helideck ID:	Santa Fe 135
Flight Phase:	Approach
Failure Category:	Installation Design
Primary Cause:	Turbulence
Secondary Cause:	N/A
Caused By:	Severe turbulence experienced during final approach to rig.
Comments:	Enclosed derrick known to cause turbulence when helideck in lee of derrick. Operating limits imposed.

Report No:	**82**
CAA SDD No:	9503696B
Year:	1995
Occurrence Type:	MOR
Aircraft Type:	Eurocopter AS 332
Helideck ID:	Unknown
Flight Phase:	Landing
Failure Category:	Installation Design
Primary Cause:	Turbulence
Secondary Cause:	N/A
Caused By:	Turbulence prior to landing. Landing circle re-sited recently. Now turbulent effects from helideck edge.
Comments:	New markings introduced for larger A/C and in compliance. Less space & net removed so poor visual cues.

Report No:	**48**
CAA SDD No:	9503569J
Year:	1995
Occurrence Type:	Accident
Aircraft Type:	Sikorsky S 61
Helideck ID:	Claymore CAP
Flight Phase:	Approach
Failure Category:	Installation Design
Primary Cause:	Flare/Burners
Secondary Cause:	Exhaust Plumes
Caused By:	Unable to arrest rate of descent as A/C crossed helideck edge. During latter stages (40 secs) of approach the A/C was engulfed by flare / GT emissions from an adjacent platform.
Comments:	A/C overtorque to 115%+. Tail rotor drive shaft severed by main rotor blades. AERAD information lacking. Helideck unrestricted prior to incident. Flare reported as primary cause but more likely to be exhaust plumes.

Report No:	**83**
CAA SDD No:	9505575D
Year:	1995
Occurrence Type:	MOR
Aircraft Type:	Sikorsky S 61
Helideck ID:	Unknown
Flight Phase:	Landing
Failure Category:	Installation Design
Primary Cause:	Turbulence
Secondary Cause:	Exhaust Plumes
Caused By:	High Rate of Descent developed as A/C crossed edge of helideck. Increased torque from 70 to 112%.
Comments:	Suspect caused by Gas Turbine exhausts. Now being assessed for presence of turbulent sector.

Report No:	**87**
CAA SDD No:	9703298X
Year:	1997
Occurrence Type:	MOR
Aircraft Type:	Eurocopter AS 365
Helideck ID:	Unknown
Flight Phase:	Hover
Failure Category:	A/C Ops
Primary Cause:	Turbulence
Secondary Cause:	Pilot Error
Caused By:	Turbulence in hover combined with use of right pedal caused transient transmission overtorque of 110%.
Comments:	Torque 85–90% as hover ht increased & a/c turn into wind. Deck problem in 3–4 ft hover, less than 15 kt wind.

Report No:	**88**
CAA SDD No:	9703493B
Year:	1997
Occurrence Type:	MOR
Aircraft Type:	Eurocopter AS 365
Helideck ID:	Unknown
Flight Phase:	Take-off
Failure Category:	Installation Design
Primary Cause:	Turbulence
Secondary Cause:	N/A
Caused By:	Momentary transmission overtorque to 106% occurred on each of 3 take-off attempts from small rig.
Comments:	Investigation being progressed under 97/03298 (See 87)

Report No:	**89**
CAA SDD No:	9505577X
Year:	1997
Occurrence Type:	MOR
Aircraft Type:	Sikorsky S 61
Helideck ID:	Unknown
Flight Phase:	Landing
Failure Category:	Installation Design
Primary Cause:	Exhaust Plumes
Secondary Cause:	Turbulence
Caused By:	High rate of descent developed as A/C crossed helideck edge.
Comments:	Airflow over deck disturbed by GT exhausts. Rig being assessed for turbulent sector.(See 9505575 – No: 83)

Report No:	**90**
CAA SDD No:	9505578J
Year:	1997
Occurrence Type:	MOR
Aircraft Type:	Sikorsky S 61
Helideck ID:	Unknown
Flight Phase:	Approach
Failure Category:	Installation Design
Primary Cause:	Exhaust Plumes
Secondary Cause:	Turbulence
Caused By:	Sudden increased rate of descent at late stage of approach. Initiated go around. Transient overtorque.
Comments:	Overtorqued to avoid deck edge. FDR indicated overtorque within manufacturers limits.

Report No:	**154**
CAA SDD No:	9806710J
Year:	1998
Occurrence Type:	MOR
Aircraft Type:	Eurocopter AS 365
Helideck ID:	Ravenspurn North
Flight Phase:	Hover
Failure Category:	Installation Design
Primary Cause:	Exhaust Plumes
Secondary Cause:	Turbulence
Caused By:	Applying take-off power from the hover (10ft) to clear platform, engine suffered ‘compressor surge’ with audible ‘popping’ noise. Turbulence encountered from platform GT Exhaust plumes.
Comments:	Two platform generators on line (normally only one). Both exhausts exit close to helideck. A/C hover outside visible hot plume as viewed during pilot walk round. Possible 2 other A/C also similarly affected, last 48 hrs.

Annex 5

SIMPLIFIED ANALYSIS OF HELICOPTER RESPONSE TO VERTICAL GUSTS NEAR HOVER

Consider a helicopter in hover or near hover subjected to a sudden vertical downdraught of strength $-w_g$, and then make the following assumptions regarding the aeromechanics of the subsequent helicopter response:–

(i) The whole rotor is instantaneously immersed in the vertical gust.

(ii) The helicopter is in the absence of ground effect.

(iii) After a delay of t_p seconds, the pilot responds by pulling in collective to achieve maximum continuous torque.

(iv) The rotor inflow changes due to gust and collective are instantaneous; in reality the uniform component of inflow builds up over a time constant of between 0.1 and 0.2 sec.

(v) The rotorspeed remains constant throughout the response; in reality the rotorspeed will droop transiently depending on the characteristics of the rotor/engine governing system.

(vi) The aircraft response can be characterised by the linearised equations of motion for the vertical velocity response w (positive down):

$$dw/dt - Z_w W = Z_w w_g + Z_{\theta 0}\theta_0(t-t_p) \qquad \text{A1}$$

where θ_0 is the rotor collective pitch angle (positive up) and the stability and control derivatives are given by the expressions:

heave damping ($m/sec^2.m/sec$),

$$Z_w = -\,2a_0\rho(\Omega R)\ (1/L_b)\ (\lambda_0/(16\lambda_0+a_0 s)) \qquad \text{A2}$$

heave control sensitivity (m/sec2. rad),

$$Z_{\theta 0} = -\,(8/3)a_0\rho(\Omega R)^2\ (1/L_b)\ (\lambda_0/(16\lambda_0+a_0 s)) \qquad \text{A3}$$

The design parameters are given by:–

$L_b = M_a/A_b$ is the blade loading (kg/m^2)
M_a is the aircraft mass (kg)
A_b is the rotorblade area (m^2)
a_0 is the mean lift curve slope of the rotorblade
Ω is the rotorspeed (rad/sec)
R is the rotor radius (m)
λ_0 is the rotor inflow normalised by rotor tip speed (ΩR)
s is the rotor solidity ($bc/\pi R$), where b is the number of blades and c is the blade chord

The response to eqn A1 takes the form of an exponential growth with time constant t_a ($= -1/Z_w$) to a steady state and can be written in two components:–

response to downdraught; $w(t) = -(1 - e^{Z_w t})w_g$ A4

response to collective; $w(t) = -(1 - e^{Z_w(t-tp)})w_s$ A5

Where w_s is the steady state response to the collective input given in m/s by the expression:

$$w_s = -(Z_{\theta 0}/Z_w)\,\theta_0 = -(4/3)\Omega R\,\theta_0 \qquad \text{A6}$$

and the maximum climb rate in hover is given:

$$hdot_{max} = (4/3)\Omega R\,\theta_{0max} \qquad \text{A7}$$

where θ_{0max} is the collective margin before maximum continuous torque is reached.

Note that the maximum rate of climb in hover is predicted by this simple theory to be a function of rotor tip speed and control margin only. It is also possible to write $hdot_{max}$ in terms of the hover thrust margin δT in the form:

$$hdot_{max} = \delta T\, g\, t_a \qquad \text{A8}$$

This expression assumes no vertical drag from the fuselage and hence, for a given thrust margin, will overestimate the vertical rate of climb. A sample calculation shows that a thrust margin of 5.1% ($\delta T = 0.051$) gives a hover climb rate of 1.5 m/s.

The aircraft time constant t_a is the inverse of the heave damping Z_w and from eqn A2 is proportional to blade loading and inversely proportional to atmospheric density and rotor tip speed. Typical values of t_a vary between 2 and 5 secs. The heave response time constant applies to both the response to gusts and collective pitch. Handling qualities augmentation will seek to reduce this parameter to enhance heave stability while ride qualities augmentation will seek to increase the time constant to reduce bumpiness.

To economise on the solution we normalise parameters as follows:–

(i) time (unit time equates to aircraft time constant); $\tau = t/t_a$

(ii) velocity: $\omega = w/hdot_{max}$

(iii) gust strength: $\omega g = w_g/hdot_{max}$

(iv) height (one height unit is the distance travelled moving at $hdot_{max}$ in an aircraft time constant): $\eta = h/(hdot_{max}\, t_a)$

(v) pilot reaction time: $\tau_p = t_p/t_a$

If it is assumed that there is a sufficient power margin to overcome the downdraught, then it is possible to derive the height lost before the rate of descent is arrested and the consequent time taken:

(i) height lost during descent; $\eta_d = \tau_p - \tau_d (1 - \omega_g)$ A9

(ii) time to zero rate of descent; $\tau_d = \log_e ((e^{\tau_p} - \omega_g)/(1 - \omega_g))$ A10

The normalised descent time and height lost are plotted in Figures A1 and A2 respectively as a function of ω_g and τ_p.

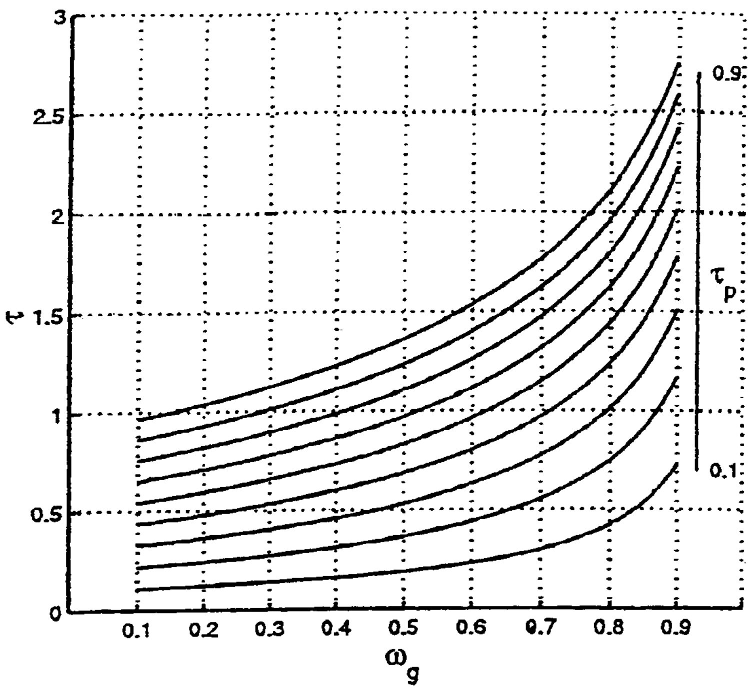

Figure A1: Normalised time to zero velocity

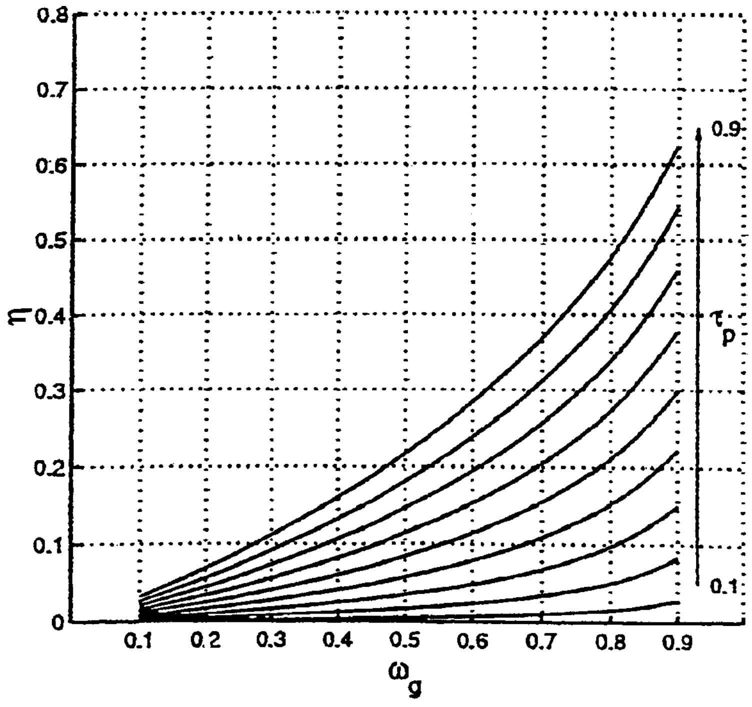

Figure A2: Normalised height lost in descent

Annex 6

HSE REGULATIONS : OFFSHORE HELIDECK OPERATIONS

Since April 1991, HSE has introduced four sets of modern goal setting regulations which contain provisions relating to helicopter movements and helideck safety on offshore installations. These update and replace the old prescriptive legislation. The provisions are as follows:

	Regulations	Covers
1	The Offshore Installations (Safety Case) Regulations 1992 (SCR) (SI 1992/2885)	**Regulation 2 (1)** defines a major accident and this includes the collision of a helicopter with an installation. **Regulation 8** requires that a safety case should demonstrate that hazards with the potential to cause a major accident have been identified, their risks evaluated and measures taken to reduce personal risk to the lowest level that is reasonably practicable.
2	The Offshore Installations (Prevention of Fire and Explosion, and Emergency Response) Regulations 1995 (PFEER) (SI 1995/743)	**Regulation 6 (1)(c)** requires a sufficient number of personnel trained to deal with helicopter emergencies to be available during helicopter movements**.** **Regulation 7** requires the operator/ owner of a fixed/mobile installation to ensure that equipment necessary for use in the event of an accident involving a helicopter is kept available near the helicopter landing area. Equipment provided under **Regulation 7** must comply with the suitability and condition requirements of **Regulation 19(1)** of PFEER. **Regulations 9, 12 and 13** make general requirements for the prevention of fire and explosion, the control of fire and explosion which would take in helicopter accidents. **Regulation 17** of PFEER requires arrangements to be made for the rescue of people near the installation from helicopter ditchings.

3	The Offshore Installations and Pipeline Works (Management and Administration) Regulations 1995 (MAR) (1995/738)	**Regulation 8** requires people to co-operate with the Helicopter Landing Officer to enable him to perform his function referred to in **Regulation 13. Regulation 11** requires comprehensible instructions to be put in writing and brought to the attention of everybody to whom they relate. Circumstances where written instructions might be needed include helideck operations particularly if involving part-time helideck crew). **Regulation 12(b)** requires arrangements which are appropriate for health and safety purposes, to be in place for effective communication between an installation, the shore, aircraft and other installations. Arrangements must also be in place for effective communication where a helicopter is to land on or take off from an installation aboard which there will be no person immediately before landing or after the take-off, between a suitable offshore installation with persons on board or where there is no suitable installation, suitable premises ashore. **Regulation 13** requires the operator/owner of a fixed/mobile installation to ensure that a competent person is appointed to be in control of helideck operations on the installation (i.e. the Helicopter Landing Officer), is present on the installation, is in control throughout such operations and procedures are established and plant provided as will secure so far as is reasonably practicable that helideck operations including landing/take-off are without risk to health and safety. **Regulation 14** requires the duty holder to make arrangements for the collection and keeping of meteorological, oceanographic and information relating to the movement of the offshore installation. This is because environmental conditions may affect helicopter operations and the ability to implement emergency plans**. Regulation 19** requires the operator/owner of an offshore installation to ensure that the installation displayed its name in such a manner as to make the installation readily identifiable by sea or air: and displays no name, letters or figures likely to be

		confused with the name or other designation of another offshore installation.
4	The Offshore Installations and Wells (Design and Construction, etc.) Regulations 1996 (DCR) (SI 1996/913)	**Regulation 11** – Helicopter Landing Area requires the operator/owner of a fixed/mobile installation to ensure that every landing area forming part of an installation is large enough and has sufficient clear approach/departure paths to enable any helicopter intended to use the landing area safely, to land and take off in any wind and weather conditions permitting helicopter operations and is of design and construction adequate for its purpose

HSE has published guidance documents on SCR, MAR and DCR and in the case of PFEER, combined guidance and an Approved Code of Practice.

The DCR which came into effect 30 June 1996, revoke the 1974 Regulations. The regime requiring installations to posses a Certificate of Fitness issued by an HSE appointed Certifying Authority are now replaced by requirements for operators/owners to introduce verification schemes in respect of the safety critical elements of their installations. The 4th Edition will be maintained throughout the two-year transitional period for the introduction of the new verification arrangements as it continues to discuss with the industry and others the future of such technical guidance.

Annex 7

MICROSENSORS FOR GAS CLOUD DETECTION

Currently, there is a potential problem with helicopters flying into gas clouds that may occasionally surround oil rigs. These clouds may contain sufficient combustible products to upset the effective operation of the gas turbine engines used to power the aircraft. The helicopter may also be an ignition source for such a gas cloud.

Effective monitoring of the large volume of the gas cloud could be best tackled by the use of a scanning laser gas detection system. Such a system has been shown to be capable of detecting gaseous pollution within several km's of land based industrial plant. The high cost of the equipment required to establish this system on the large numbers of oil rigs currently in operation, however, makes this approach unacceptably expensive.

One possible solution would be to fix a gas leak detection systems to the air intake of the aircraft's engine to monitor the composition of the air entering the engine. Alternatively, an array of gas sensors may be distributed over the superstructure of the oil rig. The information from this array, combined with previous knowledge gained from a detailed survey during a variety of conditions, may provide sufficient data to build up a physical model of gas cloud composition and its movement in the vicinity of the oil rig.

These two approaches will require the deployment of a range of sensors (chemical, humidity, pressure and temperature for example). The conditions under which they will be operated will be far from ideal, as it would seem likely that they will be subject to extreme temperatures, pressures and corrosive environments. It will also be necessary to deploy large numbers of these sensors at low cost if the system is to be useful. It should be noted that, in principle, both techniques could be used together, improving both the quality of the data gathered on the gas cloud, and the reliability of the engine based system.

Technology developed for the mainstream electronics industry is now being exploited to make and develop a range of microsensors that may be relevant to the gas cloud problem. The silicon micro electronics processing technology that is used to fabricate the microsensors means that they can be of similar size to electronic devices, that is about 5 μm in linear dimension. The same manufacturing technology can be used to produce devices that are very cheap when produced in large volumes.

There are several other features of microsensors that make them attractive. Since they are very small, it may be possible to have large numbers of them on one chip, perhaps as many as 10,000 on a chip measuring just 1 cm^2. This means that greater redundancy can be engineered into a sensor array. For example, an individual device may last for only one day, when powered, if it is subject to operation at elevated temperatures in a corrosive environment. Clearly a lifetime of just one day is unacceptable for many applications, particularly those being considered here where the sensors may be in very inaccessible positions. However, if we have 10 000 devices we may arrange to switch power to a new device each day and so increase the lifetime of the microsystem to 20+ years. The daily switching is easily achieved since active electronic devices are included in the silicon chip.

The small physical sizes of the sensors makes them attractive for low power applications. Power supply requirements may be important if a large array of sensors distributed over a large area is being considered.

The small physical size of these sensors also makes it possible to insert them into confined spaces without significantly affecting the system into which they are placed. For example, silicon sensors have been placed in structural materials without significantly reducing the strength of the material. Small sensors may also be introduced in laminar air flows, such as those found in gas turbines, without significantly disturbing the air flow.

The properties of the microsensors described above make them attractive candidates for application in the two proposed solutions to the gas cloud problem considered here. Several microsensor types that could be used in a solution to the problem are reviewed below:–

One involves a micro-machined hot-wire filament. The filament is made from deposited polysilicon and is just 1 μm thick and occupies an area of just 0.01 mm2. The filament achieves a highly incandescent state, at about 700°C, with an input power of just 30 mW.

When treated with suitable surface coatings, the filaments can become sensitive to combustible gases. As the combustible gas burns on the surface of the treated filament so the energy released raises the temperature of the filament. This temperature rise can be used to characterise the composition of the gas surrounding the filament. Greater sensitivity to the gas cloud composition could be obtained by the use of an array of gas sensors each with a different coating. Under these conditions each sensor will respond in a slightly different way to the gas cloud. The use of pattern recognition techniques allows a more precise identification of the gas cloud. Signal processing techniques such as 'Fuzzy Logic' and 'Neural Networks' may be of use here.

Due to the very small thermal mass of these structures, just a few mW are required to raise the devices to the high temperatures needed to ensure chemical sensitivity. Additionally, the small mass also leads to very short thermal time constants for the structure, typically better than 1 ms. This implies that the devices need not be run continuously. Rather they may be switched on and off with mark space ratios as high as 1:1000 while still allowing gas cloud composition monitoring to take place several times a minute. Under these conditions the average power consumption may fall to just a few μW. This is very compatible with remote battery powered operation.

It has recently been shown that these filaments can be used to detect pressure and air flow, and it is also believed that it may be possible to measure humidity and temperature with these devices. Other devices can readily be obtained to measure vibration and pressure directly.

There is considerable scope to use these sensors in both of the applications described above. However, it is necessary to raise a note of caution. It is unlikely that these micro-engineered sensors will meet the same levels of performance that are currently achieved by conventionally engineered macrosensors. This is not necessarily a problem if innovative data analysis is used. For example, the large number of microsensors can be averaged together to improve sensitivity. Also qualitative information, which may be of more relevance than quantitative information, can be readily obtained through pattern recognition techniques when a range of different sensors are used to monitor the gas cloud.

Current and future microsensor availability

The table below offers a summary of the current commercial and research status of sensors that may be of use in this application. The table is not exhaustive, but provides a current snap shot of the status.

Sensor Type	Detection of	Current commercial position	Current Research Position
Accelerometers	Acceleration and vibration	Many macro devices available. Cost $10's, detectivity to 10's µg. Micro machined devices available in discrete form. 10's mg detectivity.	Many micro devices have been demonstrated. Expect 100's µg in three years. Likely to become established commercially over the next few years.
Gas Sensors	Detection of combustible gases	Many macro devices available. Texas Instruments now market a micromachined silicon device.	Micro machined devices under investigation. There is a big commercial push here as environmental legislation comes into force and the cost saving of micromachining becomes essential.
Pressure sensors	Gas pressure	Druck currently market many micromachined silicon pressure sensors.	Other cheaper devices are under investigation for the automotive market.
Temperature	Temperature	Many.	Many, no real issues.
Humidity Sensor	Humidity	Several conventional devices.	Considerable commercial interest in developing a micro machined device.

Sensors Suitable for Helicopter Appliances

Microsensors offer considerable scope for tackling this demanding problem. It should be possible to put together a suitable demonstrator system within 12 months of this report, using a combination of commercial off-the-shelf devices and research devices already available from several UK laboratories. If the demonstration is successful, and a solid commercial case can be made for its deployment, then a microsensor-based system could be made available.