AIRCRAFT ACCIDENT REPORT 3/2004

Air Accidents Investigation Branch

Department for Transport

Report on the accident to Eurocopter AS332L Super Puma, G-BKZE on-board the West Navion Drilling Ship 80 nm west of the Shetland Islands on 10 November 2001

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This investigation was carried out in accordance with
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Department for Transport
Air Accidents Investigation Branch
Berkshire Copse Road
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May 2004

The Right Honourable Alistair Darling
Secretary of State for Transport

Dear Secretary of State

I have the honour to submit the report by Mr P T Claiden, an Inspector of Air Accidents, on the circumstances of the accident to AS332L Super Puma, G-BKZE, which occurred on-board the West Navion Drilling Ship some 80 nm to the west of the Shetland Islands on 12 November 2001.

Yours sincerely

Ken Smart
Chief Inspector of Air Accidents

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GLOSSARY OF ABBREVIATIONS USED IN THIS REPORT

AAIB	Air Accidents Investigation Branch
AI	Attitude Indicator
amsl	Above mean sea level
AOC	Air Operators Certificate
BHAB	British Helicopter Advisory Board
CAA	UK Civil Aviation Authority
CAP	Civil Aviation Publication
cm	Centimetre(s)
CMR	Certificate of Maintenance Review
CG	Centre of gravity
CVFDR	Combined Voice and Flight Data Recorder
daN	decaNewtons
DERA	Defence Evaluation and Research Agency
DG	Direct Gyro
DP	Dynamic positioning
g	Normal acceleration
HLL	Helicopter Limitations List
HLO	Helideck Landing Officer
hrs	Hours
HSE	Health and Safety Executive
HUMS	Health and Usage Monitoring System
IVLL	Installation/Vessel Limitations List
km	Kilometre(s)
kt	Knot(s)
m/s	metres per second
MSI	Motion Severity Index
MMS	Measure of Motion Severity
MODU	Mobile Offshore Drilling Unit
MPOG	Minimum Pitch on Ground
N	Newton
Nm	Newton-metre
NR	Helicopter main-rotor rpm
N_r	Engine free turbine speed
OM	Operations manual
PF	Pilot flying
psi	Pounds per square inch
RO	Radio Operator
TV	Television
UKOOA	United Kingdom Offshore Operators Association
ºM, ºT	Degrees Magnetic, True

General View of G-BKZE
Post accident

Air Accidents Investigation Branch

Aircraft Accident Report No: 3/2004 (EW/C2001/11/01)

Operator:	CHC Scotia Helicopters
Aircraft Type:	AS332L Super Puma
Nationality:	British
Registration:	G-BKZE
Date & Time (UTC):	1254 hrs on 10 November 2001
Location:	80 nautical miles West of Shetland Isles on board the West Navion drilling ship
Type of Flight:	Public Transport

Synopsis

This accident was notified to the Air Accidents Investigation Branch (AAIB) at 1320 hrs on 10 November 2001. The Investigation was conducted by Mr P T Claiden, Investigator in Charge (IIC), Mr J Blackwell (Operations), Mr A H Robinson (Engineering) and Mr R James, Flight Recorders.

The helicopter landed on the helideck of the West Navion drilling ship and was being refuelled with the rotors running. The commander remained on board whilst the co-pilot disembarked and assisted the ship's crew. About five minutes after landing, unknown to the pilot and unnoticed by the ship's crew, the West Navion's Dynamic Positioning (DP) system reverted to MANUAL heading control and the ship's heading started to drift slowly to the right. The wind at that time was westerly at 32 kt with gusts to 42 kt, and, as the ship's heading drifted, the helicopter was subjected to an increasing crosswind component. At 1254 hrs, some seven minutes after the ship's heading started to drift, the helicopter toppled over to its right. The co-pilot, who was the only person outside the helicopter on the helideck, was severely injured by flying debris as the helicopter's main rotors broke up on impact with the helideck. The helicopter came to rest on its right side and the commander vacated, with some difficulty, through the left pilot's door. Mathematical analysis of the forces acting on the helicopter indicated that the most significant toppling moments were caused by aerodynamic forces arising from the increasing lateral wind component to which the aircraft was subjected as the ship yawed to the right.

The investigation identified the following causal factors:

(i) Unknown to the crew on the bridge, the ship's Dynamic Positioning system reverted to manual heading control and the ship's heading began to drift to the right.

(ii) The increased lateral wind component to which the helicopter was consequently subjected, generated increasing aerodynamic forces to the right due to the change in the relative wind, and these forces provided the most significant toppling moments of all the forces acting on the helicopter.

(iii) The 'static' roll attitude of the helicopter adopted after landing, relative to the helideck, of 2.5° to the right, together with the lift force generated by the main rotor in the prevailing wind, the 1° list of the ship to the right at the time of the accident and the natural motion of the ship, contributed to the de-stabilisation of the helicopter.

(iv) The lack of procedures on the ship to transmit the change in the alert status to the crew of the helicopter, and of any specified procedure available to flight crews concerning action to be taken if control of the ship is lost or degraded whilst on the helideck, denied the pilot an appropriate course of action to ensure the safety of the helicopter.

Four safety recommendations have been made as a result of this investigation.

1 Factual Information

1.1 History of the flight

The aircraft was scheduled for an 0930 hrs departure from Aberdeen to transport 12 ship's crew to the West Navion drilling ship located about 80 nautical miles to the west of the Shetland Isles. The flight was planned from Aberdeen to Wick, where the aircraft was to be refuelled, and thence direct to the West Navion. The weather for the flight was under the influence of a cold front lying between the north coast of the Scottish mainland and the west coast of Norway. The front was moving south-east leaving a strong to gale force, unstable, west-north-westerly flow over the West Navion's position. Weather conditions and helideck movements recorded at 0830 hrs aboard the West Navion were sent by fax to the helicopter's operations department. These indicated a wind of 250°T/25 kt, visibility of 4,000 metres in mist and light rain, and overcast cloud conditions at 800 feet; helideck movements were within the specified operational limits for the Super Puma.

Departure from Aberdeen was delayed by the late arrival of some passengers and the aircraft eventually left at 1008 hrs. The flight to Wick proceeded uneventfully and, after loading 850 kg of fuel, the aircraft departed for the West Navion at 1119 hrs with the co-pilot as handling pilot from his normal seat on the left side of the aircraft. About 10 minutes flying time from the West Navion, the crew of the helicopter called the Schiehallion fixed installation on its 'logistics' radio frequency and requested the weather for the area and data on the West Navion's helideck movements. The surface wind for the landing was given as 285°T/34 kts with the ship's heading given as 259°T; helideck movements were within the aircraft's limits.

The crew completed the Initial Approach and Before Landing checklists which included setting the parking brake on. The co-pilot positioned the helicopter on a long final approach from the ship's left toward the helideck which was located forward of the bridge over the vessel's bow. Deck landings from the left are normally carried out by the right seat pilot and the commander therefore took control as they approached the ship. After hovering alongside to observe deck movement, the commander chose the appropriate moment, manoeuvred the helicopter over the helideck and landed. The helicopter touched down at 1242 hrs toward the forward edge of the deck on a heading of about 296°M (289°T).

It was standard procedure to carry out passenger disembarkation/embarkation and refuelling with the helicopter rotors running. The helicopter crew therefore carried out the After Landing checklist, which included disengaging the autopilot. The passengers commenced disembarkation and the co-pilot left the cockpit to assist the ship's helideck crew with the refuelling. The commander remained on board the helicopter. At about 1245 hrs the commander became concerned about the ship's movement and requested the pitch, roll and heave readings from the ship's Radio Operator (RO). After some confusion over exactly what the commander had requested the radio operator provided the readings, all of which were within the helicopter's operating limits. Nevertheless, the commander remarked that his flight instruments appeared to be showing greater movements than those recorded by the ship. Some time later, the helideck crew noticed a shift in the direction of the wind.

At 1247 hrs, unknown to the helicopter commander and unnoticed by the ship's DP operator, the ship's DP system reverted from AUTOMATIC to MANUAL heading control, and after about two minutes the ship's heading started to drift to the right. No external visual cues, such as land or a stationary ship, were available to draw the pilot's attention to this change of heading and the windsock, which would have been indicating the change in the relative wind, was not within the commander's field of vision. However, some of the helideck crew had noticed the change in wind direction. As the ship's heading increased, a list of approximately 1° to the right developed and, at about 1254:14 hrs, the DP system provided an alarm that the ship's position was out of limits. The crew responded to this alarm in accordance with their procedures and training, but the helicopter commander was not informed. Twelve seconds later, at 1254:26, the helicopter toppled over to the right.

Outside the helicopter, the refuelling was complete and three helideck crew members were re-stowing the fuel lines below the helideck. A fourth member of the helideck team was manning the controls of the foam dispensing nozzles, located at various points around the helideck, from the 'foam shack' behind the helideck. The co-pilot was the only person remaining outside the aircraft on the helideck. He had just checked that the aircraft's refuelling cap was secure and, in accordance with standard operating procedures, had completed a visual check of the right side of the aircraft. As he was subsequently walking in a clockwise direction towards the rear of the helideck along its outer edge, keeping clear of the main rotor disc, he noticed out of his peripheral vision the tail rotor starting to move towards him. He threw himself on the deck and began crawling towards a gangway that connected the helideck with the upper bridge and 'foam shack' area. As he crawled he became aware of the main rotor blades striking the deck, the engines screaming and the deck vibrating and of high velocity flying debris. At some point he felt a heavy, immobilising blow to his left leg.

The helideck crew member in the 'foam shack' saw the helicopter topple gradually on to its side and almost immediately activated the foam dispensers. The helicopter finally came to rest on its right side very close to the forward edge of the helideck having turned to the left by about 80°. The co-pilot dragged himself across the gangway on to the upper bridge area where he was given first aid treatment.

In the cockpit, the commander recalled seeing the aircraft attitude indicator reading 5° of right bank and very soon after the aircraft toppled on to its right side. Almost immediately the commander was aware of fire-fighting foam being applied to the aircraft and foam entering the cockpit. He tried to locate the General Cut-Out handle above his left shoulder, in order to shut down the helicopter's engines and systems, but from his position lying on his right side he was unable to do so. He therefore located and operated the two Fuel Shut-Off levers situated on the overhead panel and vacated the aircraft, with some difficulty, through the left cockpit door.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	Nil	Nil	Nil
Serious	1	Nil	Nil
Minor/none	1	Nil	Nil

The co-pilot's left leg was severely injured by a piece of flying debris as he crawled across the helideck. The helideck crew and embarking passengers were located on the deck immediately below the helideck and escaped injury.

1.3 Damage to aircraft

The main rotor blades had become fragmented as they struck the helideck when the aircraft rolled over. Pieces of blade debris were recovered from various parts of the ship, although much of it undoubtedly went overboard. The rotor head, blade cuffs and pitch change linkages had also suffered severe damage. The tail rotor assembly, including the gearbox, had become detached and was found on the deck at the rear of the aircraft. Four of the five blades had suffered major damage as a result of contacting the deck. The aircraft was otherwise substantially intact, with no major structural damage immediately apparent. However, crushing damage to the right side of the fuselage had extended to the right windscreen, resulting in a gap that had allowed fire-fighting foam to enter the cockpit.

The fuel tanks had remained intact, although some minor seepage from the fuel vent lines occurred for several days following the accident.

1.4 Other damage

Damage to the vessel was relatively minor, the most serious being a series of gashes, made by the tips of main rotor blades, which had penetrated the helideck. In addition, some damage occurred to the helideck lighting system and to one of the radar heads mounted on the superstructure above the bridge.

1.5 Personnel Information

1.5.1	Commander:	Male, aged 37 years	
	Licence:	Air Transport Pilot's Licence (Helicopters)	
	Instrument Rating:	Valid to 30 April 2002	
	Licence Proficiency Check:	Valid to 30 April 2002	
	Line Check:	Valid to 21 October 2002	
	Medical certificate:	Class1, valid to 14 May 2002. No limitations	
	Flying Experience:	Total all types:	7,800 hours
		Total on type:	1,800 hours
		Total last 28 days:	40 hours
		Total last 24 hours:	5 hours
	Previous rest period:	Off duty:	1455 hrs on 9 November 2001
		On duty:	0830 hrs on 10 November 2001
1.5.2	Co-pilot:	Male, aged 35 years	
	Licence:	Commercial Pilot's Licence (Helicopters)	
	Instrument Rating:	Valid to 21 June 2002	
	Proficiency Check:	Valid to 21 June 2002	
	Line Check:	Valid to 21 August 2002	
	Medical certificate:	Class 1, valid to 31 May 2002. No Limitations	

Flying Experience:	Total all types: 1,080 hours (856 hours Rotary Wing)	
	Total on type:	352 hrs
	Total last 28 days:	69 hrs
	Total last 24 hours:	6 hrs
Previous rest period	Off duty:	1635 hrs on 9 November 2001
	On duty:	0820 hrs on 10 November 2001

1.6 Aircraft information

1.6.1 Leading particulars

Type:	Eurocopter (Aerospatiale) AS332L Super Puma
Constructor's number:	2102
Date of manufacture:	1983
Registered owner:	Heliworld Leasing Limited
Certificate of airworthiness:	Public Transport (Passenger) category, issued 14 March 2000, valid until 13 March 2003
Total airframe hours:	21,022 hours
Engines:	2 Turbomeca Makila 1A turboshafts

The aircraft documentation indicated that a Certificate of Maintenance Review (CMR) had been completed on 30 October 2001, with the next one being due on 30 February 2002.

1.6.2 Helicopter crosswind limits

The Rotorcraft Flight Manual for the AS332L establishes wind limits for hover flight. The limiting factor is tail rotor authority and the wind limit varies according to the relative wind direction. There is a 35 kt wind limit for hovering flight when the wind is aft of 60° right or left of the nose. Crosswind limits for the helicopter when stationary on the ground, with the rotors running, are not established.

1.6.3 Helicopter Deck Procedures

The helicopter operator's Operations Manual (OM) describes procedures to be followed for helideck operations. Of significance to the investigation, the After Landing checklist requires the autopilot to be disengaged. Once on deck the OM Deck Procedures state the following:

> *'PF must physically monitor the controls at all times and maintain the cyclic and yaw pedals in a central position……..'*

The autopilot is disengaged to prevent it from applying cyclic or yaw control to counter deck movement and the cyclic should remain neutral, for several reasons. Firstly, any movement of the rotor disc from a position horizontal to the helideck has fatigue implications for the main rotor mast. Secondly, and more importantly, if the main rotor tips it can become a hazard to passengers and crew on the helideck. Finally, if the pilot tries to 'fly' the rotor disc to counter ship movement, and subsequently needs to apply collective control quickly for an emergency lift off, there is a risk of dynamic rollover. (In a normal takeoff with the AS332L, the left main landing gear lifts off before the right but, since this happens just as the helicopter becomes airborne, this action is not usually associated with 'rollover'. However, a rollover may be induced if there is sideways motion of the helicopter towards the wheel which remains, albeit momentarily, in contact with the surface. Such sideways motion may be caused by a crosswind and/or the lateral component of the rotor thrust, should the cyclic lever not be at the neutral position. In this situation, if the pilot attempts to hurry the takeoff by raising the collective lever, the lateral component of rotor thrust, and hence the rolling moment, is likely to increase).

The OM also states:

> *'Commanders are to ensure that while the helicopter is on a helideck rotors running, one pilot is looking out at all times, so that the HLO can attract the attention of the pilot in the cockpit, and that any helicopter movement may be perceived and corrected immediately.'*

The above requirement ensures that much of the pilot's attention is focussed outside the cockpit whilst the helicopter is on deck. Inside the cockpit, it might normally be expected that the compass should indicate a change of heading and alert the pilot, in this case, to a change in the ship's heading. However, prior to landing on an offshore installation or vessel, the helicopter gyro compass is selected to 'Direct Gyro' (DG or Free) mode, as opposed to 'Slaved' (Magnetic) mode. This is to prevent the mass of steel of the installation structure from inducing a deviation error on the compass reading. Whilst on deck with the compass in DG mode, the compass will be subject to precession and other errors, and thus will not necessarily indicate an accurate heading. Also, if there are no external features, independent of the helideck and its support installation on the ship, it may be difficult for the pilot to detect a change of heading.

The final part of the above paragraph from the OM, referring to helicopter movement, is intended to address the case of the helicopter sliding and is not intended to imply that the pilot should use the flight controls to keep the helicopter in position on the deck.

1.6.4 Weight and Balance

Aircraft weight at time of accident	6,943 kg
Longitudinal position centre of gravity	4.625 metres aft of datum (permitted range 4.4 metres – 4.9 metres) or 45% aft
Vertical position of centre of gravity	2.1 metres above deck
Lateral position of centre of gravity	+0.0064 metres (permitted range Left –0.08 to Right +0.09) or +7%

1.7 Meteorological information

1.7.1 The Forecast

The Forecast Significant Weather for the Northern North Sea below 10,000 feet amsl, issued at 0403 hrs and valid from 0500 hrs to 1200 hrs on 10 November 2001, showed a cold front orientated roughly northeast/southwest between the Orkneys and the west coast of Norway at 1200 hrs. The West Navion was located to the north-west of this front and the forecast for this area gave 30 km visibility below a broken layer of cumulus or strato cumulus cloud, base at 2,000 feet with tops at 5,000 feet. Isolated showers of rain were forecast to reduce visibility to 15 km and reduce the cloud base to 1,800 feet. Moderate or severe turbulence and moderate icing were forecast below FL60. At 500 feet the forecast wind for the period 0600 hrs to 1200 hrs was 260°T/35-40 kt.

1.7.2 The Aftercast

An Aftercast issued by the Meteorological Office for the period covering the time of the accident, gave a surface wind for the West Navion of 270°T/32-42 kt. The Aftercast observed that it was difficult to give an accurate indication of gusts aboard a ship since the wind tends to gust around some parts of the superstructure differently from others. The Aftercast further stated that the maximum gust of 42 kt should be regarded as a guide to that which was possible in the airmass.

1.7.3 Other sources of data

Other sources of wind data included a screen print from the West Navion's DP console, a reading from the nearby safety vessel, the Faroe Connector, and readings from the Foinaven fixed installation located about 10 miles south south-east of the West Navion. The West Navion screen print provided filtered information in graphical form over a one hour period. At about the time the helicopter landed the wind direction averaged 270°T and this backed to 260°T at the time of the accident. The windspeed averaged 26 kt at the time of the accident but, since peak readings were mathematically filtered, this speed took no account of gusts. The Faroe Connector was acting as safety vessel and was about 500 meters from the West Navion when the accident occurred. The recorded wind on board the Faroe Connector was 250°T/37 kt, but no information was available on wind gusts or on the height at which the wind was recorded. Data from the Foinaven showed an average wind direction of 280°T and average speed of about 37 kt, with gusts to 45 kt.

1.8 Aids to Navigation

Not applicable.

1.9 Communications

The UK Offshore Operators Association (UKOOA) publishes Guidelines for the Management of Offshore Helideck Operations which are used by installation and vessel operators to develop the required Safety Case for helicopter operations and in the development of Safety Management Systems. The Guidelines have been produced in consultation with the CAA, British Helicopter Advisory Board (BHAB) and the Health and Safety Executive (HSE) and are generally regarded as industry 'best practice'. The operators of the West Navion had written procedures concerning helicopter operations from the ship.

On the West Navion, communications with helicopters were normally conducted by the ship's RO or the Helideck Landing Officer (HLO). The RO was responsible for sending a weather report to the helicopter's base before the flight, including pitch, roll and heave information, and for updating weather every 30 minutes during the flight, and when there was any noticeable change. Initial and final contact between the helicopter and the ship was normally through the RO; however, the RO was located beneath the helideck on the ship's bridge with no direct visual contact, although there was a TV monitor on the bridge which displayed a restricted view of the helideck. It was therefore normal procedure for the HLO to take over communication with the helicopter via a portable radio once he was satisfied that the deck was cleared for landing. On this occasion, however, the helicopter had difficulty in establishing radio communications with the HLO, and communications were therefore conducted through the RO. Similar difficulties were encountered the previous day.

The RO's position on the bridge was between, and to the right of, two parallel consoles from where the ship is controlled when underway and when drilling. Weather, pitch, roll and heave information were normally available from a computer screen on the forward console. However, on the day of the accident, this screen was out of service and the RO had to use the information from the rear consoles, which were in use by the DP operator. Neither the forward computer screen nor the DP consoles were easily visible from the RO's position and it was necessary to leave the radio equipment and walk to either position to view the data. In addition, much of the information on the DP screens is factored or averaged for use by the DP computers, and the basis of the data presented on the screen was not immediately evident. When the commander of the helicopter requested pitch, roll and heave information whilst sitting on the helideck, the RO had to leave his station, walk to the DP operator's position and ask for the requested data.

The UKOOA Guidelines provided guidance on helideck emergency procedures for various credible scenarios including "Installation Status Change With Aircraft on Deck". At the time of the accident, the following note was included in paragraph 3.2.3, which referred to Aircrew and Helideck Crew Duties and Procedures From Initial Contact To After Take Off:

> *'Offshore installations should have a procedure whereby any helicopter on deck is informed of any change in installation alert status. For example it may, depending on the circumstances, be necessary to order the aircraft to either take off or shut down in the event of an alert due to a gas leak.'*

The recommended response to a status change was for the HLO to contact the Offshore Installation Manager, Master or Radio Room to receive further instructions. The West Navion's helicopter procedures document did not include the emergency procedure described above. Since this accident, UKOOA Guidelines have been amended to include the following, in addition to the note previously contained in paragraph 3.2.3:

> *'In the case of floating structures and vessels, a loss of heading control (eg loss of Dynamic Positioning (DP)) or a significant change in motion characteristics must immediately be notified to the flight crew. This change in conditions may require the flight crew to prepare for*

immediate lift-off if the helideck motion limits or helicopter limits of operability are likely to be exceeded.'

1.10 Aerodrome information

1.10.1 General

Annex 14, Volume II, to the Convention on International Civil Aviation outlines International Standards and Recommended Practices in respect of heliport planning, design and operations. The CAA publication CAP 437 gives guidance on the criteria applied by the CAA in assessing the standard of helicopter offshore landing areas for use by helicopters registered in the United Kingdom. A UK registered helicopter shall not operate to an offshore helicopter landing area unless the helideck has been authorised and properly described in the Operations Manual. The task of helideck inspection has been delegated by the Operators to a sub-committee of BHAB, who are audited by the CAA. Subject to a satisfactory inspection, the BHAB will issue a "Helideck Certificate" valid for a maximum of three years and any items from the BHAB's inspection report that require limitations to be placed on operations, are published in the Installation/Vessel Limitations List (IVLL), now known as the Helicopter Limitations List (HLL).

1.10.2 Helideck limitations

The IVLL categorises helidecks on ships and platforms into groups, according to their likely movement characteristics, and provides pitch, roll and heave limits for each helicopter type likely to be flown to that group. The West Navion is classified as a Code C, Large Ship and operations of the AS332L to the West Navion are limited to 2.5° of helideck movement either side of the pitch and roll axes and four metres of heave in the vertical axis. Maximum rates of movement are not quoted.

CAP 437 indicates that reports to helicopters on pitch and roll should:

> *…..'include values, in degrees, about both axes of the true vertical datum (ie relative to the true horizon) and be expressed in relation to the vessel's head.'*

Roll should be expressed as '*left and right*', and pitch '*up and down*'. Heave, being the vertical difference between the highest and lowest points of any single cycle of the helideck movement, should be reported as 'a single figure in metres'. The parameters reported should be the maximum peak levels recorded during the ten minute period prior to commencement of helicopter deck operations.

The system, described above, for classifying helidecks and imposing pitch, roll and heave operating limits has been in use for many years, and was derived empirically rather than by scientific analysis. The CAA has recognised the limitations of the current system, particularly since no account is taken of the accelerations imparted by helideck movement to the helicopter after it has landed. For some years the CAA has been sponsoring research into the measurement of the motion and acceleration forces of moving helidecks and the impact of such forces on helicopters on deck. Operating limitations in future are likely to be based on a Motion Severity Index (MSI) derived from helideck accelerometers, and the system will include software to provide a statistical prediction of helideck movement for a defined period of time.

1.10.3 The West Navion Helideck

The West Navion is a drilling vessel designed to operate in deep water without the use of anchors. The helideck is located above and forward of the navigation bridge over the bow. It is designed to take a helicopter of maximum weight 14,290 kg and is 113 feet above sea level. The BHAB had last inspected the ship on 22 March 2001 and the Helicopter Landing Area Certificate was valid until 21 March 2004.

1.10.4 The West Navion Dynamic Positioning System

The vessel's position over the well head fixed on the seabed was maintained by a simplex computer controlled DP system which determined position from navigation satellites and sea-bed transponders, and which utilised electrically powered thrusters to maintain station. The DP system was programmed to take account of the prevailing sea current and wind to maintain station. The DP system is normally operated in AUTOMATIC mode but has a manual reversion capability. MANUAL control is selected via a 'one-touch' switch. In AUTOMATIC mode, the DP system gives the operator a warning if the ship's heading deviates more than $\pm 2°$, and an alarm when it deviates by more than $\pm 3°$. In MANUAL mode no warnings are given and the only indication to the DP operator that the system is operating in MANUAL mode is the absence of a heading window on one of his DP screens. The 'out of position' alarm that eventually alerted the DP operator to a problem on this occasion, is set to provide warning that the vessel has moved off station to the point where there is a risk of problems with the drilling riser, the connection from the wellhead to the vessel. The operation of the DP system is monitored by a DP operator, who works a twelve-hour shift, six of which are spent monitoring the DP system.

1.10.5 Failure of the DP system

The problem with the DP system falls outside the scope of this investigation but was included in an investigation carried out by the HSE following the accident. However, a system failure is not an unknown event and a similar loss of heading had occurred on 12 October 2001.

If a loss of heading develops to the point where the ship's thrusters can no longer maintain station, a loss of position can result. Severe damage can occur if a timely disconnect from the riser is not made in the event of a loss of position, and systems and procedures have therefore been developed to deal with such an emergency. As a result of the loss of position involved in this accident an emergency riser disconnect was carried out at 1259:22, about five minutes after the helicopter rolled over.

Although there was no AAIB investigation into the West Navion's systems, the Dutyholder (Installation Operators) commissioned their own investigation into the DP failures that occurred on 12 October and 10 November 2001. Their investigation concluded that the circumstances of the two events were similar in that they both started with a loss of automatic heading control, followed by a change of heading to the right. They noted that no DP electronic data-logging was available on this vessel. Detailed trend analysis was therefore restricted to 'screen shots' from the DP console, which are not ideally suited for this purpose. The relevant screen shot is presented in Appendix A, Figure 1. Nevertheless, their report indicated that on both occasions, at about the time that directional control was lost, the DP system was applying a turning moment in the wrong direction relative to the selected heading. This gave rise to the possibility of a software failure having occurred, although the investigation could not decide whether this, or operator intervention was responsible for the loss of control. Certainly, tests conducted by the vessel operator in conjunction with the DP system vendor could not find any evidence of a system failure.

The investigation recommended that the Dutyholder establish a requirement to formally analyse and closeout all station keeping related incidents. The Dutyholder believed that the two West Navion incidents exposed a gap in the framework for managing these types of events and that the 10 November 2001 DP incident may have been avoided if sufficient effort had been made into investigating the loss of position incident which took place on 12 October.

The Dutyholder's report did not attempt to address the issue of whether the station keeping incident fully or partially led to the accident to G-BKZE. However, it stated that:

> *'…(if) the DP incident is in any way a contributory cause in the air accident, then it is reasonable to suggest that preventative actions taken post 12 October to prevent the heading loss incident may have prevented the air accident.'*

Following the 12 October event, actions had been identified for implementation on the West Navion, including the installation of a 'double touch' switch to prevent inadvertent mode changes of the DP system. However, the installation of the switch had not been accomplished by the time of the accident to G-BKZE.

1.11 Flight Recorders

1.11.1 General

The Combined Voice and Flight Data Recorder (CVFDR) fitted to G-BKZE used magnetic tape as the recording media. The recorder retained eight hours of flight data and one and a half hours of three audio channels (commander, co-pilot and cockpit area microphone). The helicopter was fitted with a Health and Usage Monitoring System (HUMS), but the associated data proved of no value in this investigation.

Once the helicopter had been recovered after the accident, a calibration of the transducers for the recording of the collective, cyclic and yaw pedal positions was carried out by the operator to improve on the accuracy of interpretation of the recorded data for these parameters. Wind speed and direction parameters were not amongst the data set recorded by the CVFDR.

1.11.2 Prior to landing

The helicopter departed Wick at 1119 hrs and the flight was uneventful. At 1203 hrs the crew obtained the wind for the West Navion and this was given as 285° at 34 kt. Later, at 1222 hrs, they requested the pitch, roll and heave figures and these were quoted as being ± 0.9° in pitch, ± 0.5° in roll and 3.3 metres of heave. They were also passed the wind direction (285°T) and the heading of the ship (259°T).

At 1225 hrs, the West Navion asked for the passengers to be disembarked two at a time due to the prevailing weather conditions. The commander announced to the passengers over the public address that the West Navion deck was moving around and was quite windy, quoting wind speeds of between 40 kt to 45 kt. He relayed the request for them to disembark two at a time for these reasons. The approach checks were then carried out and the brakes selected on prior to the landing.

1.11.3 Landing

The helicopter landed just before 1243 hrs on a heading of 296°M (289°T), 4° right of the last reported wind. It touched down, right gear first with a roll attitude of 3.2° to the right. The helicopter yawed slightly left as the oleos compressed and the collective was lowered to the Minimum Pitch On Ground (MPOG) position. The autopilot was disconnected at touchdown. The recorded values of roll attitude showed that the helicopter, after landing, had developed an average list to the right of approximately 2.5°. Superimposed on this average list to the right were the roll excursions induced by the motion of the helideck. Graphical traces of the salient parameters recorded whilst on deck are shown in Appendix B, Figures 1a and 1b.

1.11.4 After landing

During the time that the helicopter was on deck, the cyclic control remained essentially neutral and the collective at MPOG with the rotors running at 96% NR. Some yaw pedal movement was recorded during this period and ranged from 68% after landing to 56% just prior to the accident, where 0% is defined as full right pedal and 100% is full left pedal. In addition, although the airspeed recording system is not as accurate below 50 kt as it is above this value, the long term average of the recorded values, from 1242 hrs to 1249 hrs, was approximately 35 kt, with minimum and maximum readings of 7 kt and 46 kt respectively.

At 1244 hrs, once the post landing checks had been carried out the co-pilot vacated the helicopter to supervise the rotors running refuelling. A minute and a half later the commander radioed the West Navion and requested the pitch figures for the ship. The West Navion radio operator advised him that the ship was rolling ± 1° at that time. Having reiterated his request for pitch, the commander was passed figures of ± 1.2° in pitch, ± 0.4° in roll and a heave of just below 4 metres. The commander, after looking at his instruments, stated that it was "clearly more than that" and quoted figures that he was seeing of 2° either way in pitch and 1.5° either way in roll. (The Attitude Indicator is calibrated in roll at intervals of 10° below 30°.) This entire exchange took over three minutes, as the West Navion radio operator's usual console displaying this information was turned off for maintenance work and he had to obtain the requested data from a more remote source. During this time, the peak recorded values of helicopter pitch ranged between + 0.4° and + 2.9° whilst the corresponding peak values of helicopter roll were + 1.5° and + 3.5°. Graphical traces of the pitch and roll recordings of the helicopter at the time of the communications are shown in Appendix B, Figure 2.

All of the time that the helicopter was on deck the CVFDR recording showed cyclic oscillations in the values of pitch, roll and the three accelerometer axes (normal, longitudinal and lateral). The period of the oscillations was approximately 10 seconds and was consistent with the wave period of the sea at that time. It was also noted that, from the time of landing at 1242 hrs until 1249 hrs, the relative phase of the waveforms of the normal and lateral acceleration recordings were such that lateral led normal by approximately a quarter wave period. An extract of the recorded data to illustrate this is shown in Appendix B, Figure 3a.

1.11.5 Loss of ship yaw control

At 1249 hrs, the recorded heading of the helicopter, which had remained relatively constant at 296°M (289°T) until that time, began to increase. The increase was initially at a rate of 2.8° per minute, but slowly accelerated over the next six minutes to a rate of 11° per minute. As heading increased, the initial 2.5° right roll offset began to increase. In addition, the average of the recorded airspeed values began to decrease as the helicopter began to head more out of wind. A graphical illustration of these observations is shown in Appendix B, Figure 4.

At 1252 hrs, with helicopter heading having increased to 306°M (299°T) and the average right roll offset having increased to 2.75°, the commander filed the flight plan for the return sector. It was also observed that the relative phase of the normal to lateral accelerations was changing, to bring the lateral acceleration peaks more in phase with those of normal acceleration. By the end of the recording, the peaks of normal acceleration were predominantly in phase with those of lateral acceleration. A sample period to illustrate this is shown in Appendix B, Figure 3b.

1.11.6 Helicopter rollover

By 1253 hrs, the average right roll of the helicopter had increased to 3.0° (an increase of 0.5° over the initial offset) and heading had increased by 20°, from the landing heading to 316°M (309°T). Over the next minute and a half the rate of average roll offset increased until, at 1254.22 hrs, the instantaneous roll attitude was recorded at a minimum of 3.5° right before increasing rapidly as the helicopter toppled to the right. During this final roll to the right, the recorded values of normal acceleration decreased from a peak reading of 1.08 g to a minimum of 0.89 g as the roll attitude increased through 6°. The rate of roll attitude increase as the helicopter fell over was such that the recorded values changed from 7.6° to 41.7° over a period of two seconds. At the time that it toppled, the heading of G-BKZE was 330.9°M, (323.9°T) an increase of nearly 35° over that of the original heading at landing.

Just prior to, and during the toppling, there were no recorded movements of the cyclic or collective controls. However, as roll attitude increased through 41°, the final recorded sample of yaw pedal showed that the left pedal was being depressed. The data and voice recordings terminated simultaneously as electrical power was removed from the CVFDR due to the activation of the 'g switch' fitted to the system. It is considered likely that, as the main rotors began to strike the deck, sufficient accelerations were developed to activate this switch.

1.12 Wreckage and impact information

1.12.1 Accident site details

The helicopter had come to rest on its right side, on a heading of approximately 50° to the left of the fore/aft centreline of the helideck. The CVFDR data indicated that the landing had been some 30° to the right of the ship's heading, it was therefore apparent that the aircraft had rotated approximately 80° relative to the ship during the accident sequence. The main rotor blades had struck the aluminium surface of the helideck, penetrating the decking in three places; these impact marks were broadly parallel to the ship's longitudinal axis. The positions of the blade strike marks are shown on Appendix A, Figure 2. It can be seen that, in order for the blades to have struck the deck in the observed positions, the aircraft most probably toppled about a line joining the right main and nose landing gears.

The deck netting had become tightly entangled around the rotor head as the drivetrain wound down, and it was evident that this had caused the helicopter to winch itself anticlockwise along a circular path.

The deck netting on helidecks is provided as an anti-skid measure, and in this case took the form of a 20 cm rope mesh. A single strand of the rope was broken where it crossed the central bar of the 'H' symbol painted on the deck. There was additionally a short skid mark, approximately 20 cm in length, made by the tyre on a raised butt-strap that joined together two sections of decking, also on the bar of the 'H'. This was thought to be a reliable indication of the position of the right main wheel at the moment the aircraft toppled over. There was no evidence that there had been any extensive sliding associated with the event.

1.12.2 Examination of the aircraft

1.12.2.1 General

Inside the cockpit it was observed that the landing gear selector was in the DOWN position and the parking brake applied. The engine speed select levers were found in the aft (retarded) positions; they had been moved there as a consequence of the commander operating the emergency fuel shut-off levers, which closed the engine fuel cocks. The collective pitch lever was found in its fully down position. It was possible to confirm that the flying control system had remained connected between the cockpit controls and the servo actuators but the pitch change rods to the main rotor blades were all fractured. This was consistent with abnormally high forces in the rods generated by the blades striking the deck after the aircraft had toppled over.

1.12.2.2 Landing gear

Each main landing gear consists of a wheel unit attached to a trailing arm, which in turn is mounted on the lower fuselage ahead of the wheel. The oleo-pneumatic shock strut, incorporating the retraction jack, is attached between the lower end of the trailing arm and a point on the side of the fuselage. The attitude of the Super Puma in the hover is slightly right wheel low, with the result that the right main wheel invariably touches down before the left. In accordance with normal procedure, the parking brake is applied prior to landing and, any forward motion associated with this causes the right wheel to 'drag', rotating the radius arm and slightly compressing the oleo. The absence of dragging of the left wheel at its subsequent touchdown results in differential compression of the left and right oleo-pneumatic struts, which in this case amounted to a bank angle of some 2.5° to the right relative to the helideck, as recorded by the CVFDR.

The potential for a technical defect in the landing gear, including the wheels and tyres, to have contributed to the event was thought to be limited, and probably confined to deflated tyres and oleos causing the aircraft to list to one side. In fact it was found that the right main wheel tyre and the right nose wheel tyre were both under-inflated (60 psi for each, against the specified values of 120 psi and 95 psi respectively), although neither was apparently leaking at the time of the examination. The left main wheel tyre was slightly under-inflated at 100 psi, and the left nose wheel tyre was slightly over-inflated at 100 psi.

The absence of continued leakage led to the conclusion that the reduced pressure on the right side tyres was the result of the tyre beads being momentarily pushed away from the wheel rims due to the high lateral forces that undoubtedly occurred during the toppling process.

The main landing gear oleos, or shock struts, were also checked for internal pressure (although as the right hand unit was inaccessible with the aircraft lying on its right side, it could not be checked until the aircraft was off-loaded at Stavanger). These were found to be around 13.1 bar, against the maintenance manual figure of 14 bar.

1.13 Medical and pathological

Not applicable.

1.14 Fire

Not applicable.

1.15 Survival aspects

1.15.1 Commander's egress from the helicopter

The helicopter came to rest on its right side with the right mainwheel sponson supporting the base of the fuselage above the deck (110° right roll), and the commander found himself lying on his right side against the right cockpit door. The helideck crew member manning the 'foam shack' was extremely prompt in activating the foam dispensers and very soon after the helicopter rolled it was being covered in foam. This had the effect in the cockpit of obscuring outside vision and reducing the amount of available light. Moreover damage to the helicopter forward windscreen allowed foam to enter the cockpit which made internal surfaces slippery. As a consequence the commander experienced considerable difficulty in exiting the aircraft through the left cockpit door using the left Fuel Control Lever and left seat as hand and foot holds.

1.15.2 Co-pilot's rescue

The co-pilot was given prompt and effective first aid treatment by the West Navion's medically qualified crewmember, but he required evacuation to hospital. A rescue helicopter was dispatched to take both crew members to shore, but since the helideck was not useable for normal operations due to the presence of the wreckage of G-BKZE, they needed to be winched aboard from the stern of the ship. The co-pilot was placed in a stretcher and man-handled the length of the ship, a process that caused him considerable pain. Having reached the stern the wind conditions were found to be too turbulent for winching (due to the effects of the ship's superstructure) and the journey had to be reversed. They were eventually winched aboard the rescue helicopter from the bow of the ship, adjacent to the helideck.

Since the accident, UKOOA Guidelines for the Management of Offshore Helideck Operations have been amended to include a requirement for….

> *'vessel owners to identify areas on their facilities that are suitable for winching in the event that the helideck or designated winching area (on vessels without helidecks) becomes inaccessible to helicopters or personnel. '*

1.16 Tests and Research

1.16.1 General

From the outset of this investigation there appeared to be no evidence for a mechanical defect in the helicopter contributing to the accident. The main investigative effort was therefore directed towards attempting to understand the forces to which the aircraft was subjected as the ship yawed to the right, following the loss of the heading control within the ship's DP system.

1.16.2 Mathematical modeling of the event

Following discussions with various organisations, two companies were selected to conduct analyses of the forces acting on the aircraft up to the time of the toppling event. For this, each company used independently developed mathematical models of the helicopter, augmented by aerodynamic data supplied by Eurocopter, the manufacturer. Inputs to the model included the CVFDR data (ie the aircraft attitude and accelerations in all three axes) and wind parameters selected from the assessment in Section 1.7. In addition, the manufacturer had their own aerodynamic and mathematical models, which they used to monitor and comment on the progress of the investigation. The two companies selected were QinetiQ (an arm of the former Defence, Evaluation and Research Agency (DERA)) and W S Atkins.

QinetiQ has many years of experience of simulation and analysis of helicopter flight in various operational environments, and their capabilities have been developed in support of Ministry of Defence and CAA research projects. Their basic helicopter mathematical model has been validated against a range of aircraft types and similar simulations used elsewhere in the industry. They were supplied with additional data on the main and tail rotor blade systems of the AS332L, which were used to calculate the rotor thrusts throughout the time the aircraft was on the helideck.

W S Atkins was contracted after the QinetiQ analysis had been completed, following critical evaluation of the results. As well as providing a useful validation of the results, it was felt that some additional work was required, including consideration of the possibility that the helicopter started to slide before it toppled over. The previous experience of both QinetiQ and the manufacturer of analytical models was that they predicted main rotor negative thrust values at low collective pitch angles near the ground. However, the manufacturer's calculations include the weight of the Main Rotor in the overall lift values, meaning that the main rotor actually was predicted to generate a small positive value of thrust at MPOG, but insufficient to overcome the weight of the rotor. As it was considered unlikely that the calculations reflected reality, W S Atkins adopted a different approach. Instead, they used estimates of rotor thrust based on trials data gained during research for the United Kingdom CAA on helicopter operations to moving decks. The purpose of this research was to develop the MSI, which will eventually replace the current pitch, roll and heave limits.

A synopsis of their analyses is contained in Appendix C but, in summary, it was calculated by both organisations that the most significant toppling moments experienced by G-BKZE were caused by aerodynamic forces arising from the increasing lateral wind component to which the aircraft was subjected as the ship yawed to the right.

1.17 Organisational and management information

Responsibility for the safety of UK based offshore helicopter operations involves a variety of different organisations. These responsibilities are comprehensively outlined in the UKOOA Guidelines for the Management of Offshore Helideck Operations, and are summarised below.

The key organisations include the oil and gas companies, who finance offshore activities and act as Dutyholders, but they also contract the services of Mobile Offshore Drilling Units (MODUs), vessels and helicopter services. Helicopter operators (AOC holders) provide contracted services. The HSE regulates the safety of offshore installations in accordance with the Health and Safety Act 1974, while the CAA regulates the safety of helicopter operations in accordance with the UK Air Navigation Order, various Civil Aviation Publications (CAPs), and the European Joint Aviation Requirements, JAR-OPS 3. Offshore installations operating within designated areas under the Continental Shelf Act 1964 must comply with the relevant UK offshore and aviation legislation, but MODU or vessels will also operate under 'Flag State' rules (appropriate to the Port of Registration), international agreements and local aviation rules. These will change according to the part of the world in which they operate. The varying responsibilities can cause confusion.

In the case of this accident, the West Navion had been chartered by an oil company operating from the UK to carry out drilling exploration. The oil company also had a contract with a UK helicopter operator to provide helicopter services to the vessel. The ship was on the edge of the UK Continental Shelf, and therefore subject to State of Registration and international regulations. G-BKZE, however, was subject to UK aviation rules and CAA regulation.

1.18 Additional information

Not applicable.

1.19 New investigation techniques

Not applicable.

2 Analysis

2.1 Introduction

The accident occurred to G-BKZE 12 minutes after landing on the West Navion. Early in the investigation the engineering examination revealed no fault in the helicopter that might have caused or contributed to the accident. The weather conditions were demanding but within specified operating limits, and the initial phase of the investigation focussed on the possibility that the IVLL pitch, roll and heave limits were exceeded when the West Navion lost heading control. Having ascertained that this had not been the case, the investigation concentrated on the combination of aerodynamic and inertial forces to which the helicopter had been subjected. This analysis begins with a review of the initial phase of the investigation conducted using the evidence of the CVFDR and goes on to consider the results of the mathematical studies and the operational aspects of the investigation.

2.2 CVFDR Analysis

During the period that G-BKZE was on deck, before the West Navion lost yaw control, the peak values of lateral and normal acceleration were generally not coincident. The highest values of normal acceleration (when the helicopter had the highest apparent weight) occurred at the bottom of the heave cycle, ie when the helideck was starting to move upwards. Correspondingly, the lowest normal acceleration values occurred at the top of the heave cycle. At that point, the helicopter would have had the lowest apparent weight and therefore the lowest stability in the absence of any other influence. The effect of lateral accelerations (in either direction) also act to destabilise the helicopter. A simple calculation based on the moment arms of these accelerations showed that, on their own, the small values recorded fell well below the magnitude required to topple the helicopter. The relative phase of the lateral and normal accelerations recorded is considered to be a function of the relative direction of the sea wave action with respect to that of the ship and the consequent induced motion of the ship. As can be seen from the graph shown in Appendix B, Figure 3b, once the ship heading changed, the relative phase of the accelerations changed. Once the low peaks of normal acceleration became coincident with the most negative peaks (acceleration to the left) of lateral acceleration, the peak destabilising effect of acceleration to the left occurred at the same time that the helicopter had the lowest apparent weight.

In summary, the helicopter would have been less stable once these acceleration peaks became coincident, but it is important to emphasise that this effect in isolation was insufficient to cause the helicopter to topple over.

2.3 Mathematical analysis (reference Appendix C)

In attempting to analyse the dynamics of the accident by numerical methods, it became apparent that the various agencies involved came up with differing 'solutions', despite the fact that all were working from a common set of input data. Confidence in the results is dictated as much by uncertainties in the input data as by the mathematical methods employed. Probably the most significant among these uncertainties was the exact wind speed at the time the helicopter toppled over. The West Navion's recording of the wind filtered out short-term gusts and the aircraft pitot static system, as with all helicopters, becomes unreliable at high sideslip angles. The mathematical studies were therefore conducted in order to assess the likely forces to which the aircraft was subjected after landing on the helideck.

Assumptions made for the calculations varied from one agency to another. For example, the W S Atkins study ignored tail rotor thrust and main rotor flapping moments, whereas these were included by QinetiQ and Eurocopter. Any contributions from these sources would, in the W S Atkins case, simply require slightly less rotor thrust at the toppling limit. The reasons for ignoring them were based on data collected during field trials which, additionally, made the case for assessing the main rotor thrust to be around 2,000 daN in the prevailing wind conditions. This value is not insignificant, representing around 30% of the aircraft weight at the time of the accident.

The QinetiQ study initially indicated that the main rotor thrust was approximately 55% of the aircraft weight, which was developed at vertical wind velocity components of up to 10m/s. Such a magnitude of upwash is not credible, although it must be remembered that it was interpolated from the analytical model's prediction of negative lift at MPOG with zero vertical wind component. Since the W S Atkins trials had dismissed the possibility of negative lift, and if it were possible to substitute a mathematical model that reflected this, ie, by moving the lift curve in Appendix C, Figure 1b, up the vertical axis, then the upwash value would most probably have been significantly less. When the QinetiQ modelling was repeated using the same wind speed and direction as used by W S Atkins, the derived main rotor thrust reduced to approximately 32% of the aircraft weight, at upwash values of 4.5 m/s. The issue of vertical velocity component on helidecks nevertheless remains contentious. It is difficult for example to reconcile QinetiQ's assessment of 5 m/s vertical component in a 12 m/s horizontal airflow, as measured at the edge of a helideck, with 0.9 m/s in a 25 m/s wind as stated in CAP 437. The only certainty is that rotor lift is sensitive to vertical velocity component.

Following the repeat of the QinetiQ study with the revised wind conditions, the derived main rotor thrust, at 2,227 kg agreed reasonably well with the W S Atkins figure of 2,000 daN (2,038 kg). Some differences inevitably arose from the methods used by each agency in treating the lateral acceleration elements during the modelling process. Despite the differences however, the research generally indicated that the AS332L main rotor develops a significant amount of lift whilst on the ground with minimum collective pitch applied. Furthermore, additional thrust can result from combinations of windspeed, vertical velocity and aircraft orientation with respect to the wind. In consideration of the destabilising effect, in terms of toppling or sliding, of lift acting on a helicopter on the ground, it seems probable that helicopters may be more vulnerable than previously appreciated. It is also probable that helicopters other than the AS332L could be similarly vulnerable by virtue of main rotor lift. Indeed, the lift developed by the Sikorsky S76 when on the ground is known to be approximately 30% of its weight in a 20 kt wind.

Additionally, the W S Atkins work indicated that sliding, in an anticlockwise direction about the nose wheel, could have occurred before the onset of tipping, although these were effectively coincidental.

Throughout the period G-BKZE was on the helideck, the ship's motion changed slightly in that the roll occurred about a mean that had become displaced approximately 1° to the right of vertical. This was assessed from the DP screen printout, Appendix A, Figure 1. A large vessel, such as the West Navion, is less susceptible to wave motion than a smaller one in terms of pitch and roll attitudes. Although the exact landing gear oleo deflection, relative to the helideck, at any one time is not known, the average values suggest that at no time did the ship exceed its limits of 2.5° either side of its pitch and roll axes. Thus, although the inertial effects acted to destabilise the aircraft, they were no more severe than those encountered during many normal operations. Mathematical analysis of the forces acting on the helicopter, however, indicated that the most significant toppling moments were caused by aerodynamic forces arising from the increasing lateral wind component to which the aircraft was subjected as the ship yawed to the right.

At some point in the future, it is anticipated that the current IVLL limits for pitch, roll and heave will be replaced by a MSI. The IVLL limits, although somewhat arbitrary, seem to have served the industry well. Perhaps one of their major shortcomings was that they only considered ship, and hence helideck, attitudes. Helideck accelerations on large vessels can be considerably greater than for smaller ones if the helideck is positioned far from the pitch and roll axes, for example high up and/or on the bow. The proposed MSI system appears sensible in that it will establish scientifically derived limits for helicopter operations to moving platforms. At the heart of this system is the Measure of

Motion Severity (MMS), (reference Appendix C), which is defined by the ratio of horizontal to vertical forces acting on the aircraft as a result of deck inclinations and accelerations, and which can be expressed as the tangent of a 'dynamic deck angle'. The MSI will be factored to represent the maximum likely deck motion during the time the helicopter remains on deck, based on preceding MMS data prior to landing. Safe operational limits will be defined as a function of MSI, wind speed and direction. The conditions that obtained when G-BKZE landed on the West Navion were by no means exceptional and there is no reason to suppose that a prohibitive MSI would have been generated had this system been in place.

As noted earlier, Main Rotor lift has a destabilising effect, principally as a result of reducing the vertical reaction on the helideck, thus increasing the MMS value. Limiting values of MMS are likely to differ according to aircraft type, and are strongly dependent on the aircraft geometry. The ASA332L Super Puma features predominantly in the current CAA research because, of the aircraft types currently operated in the North Sea and Continental Shelf Areas, it has the most limiting stability. This assessed by the ratio of the height of the centre of gravity (CG) to the landing gear track. It is therefore crucial that the destabilising effects of the lift and drag forces be factored carefully into the MSI process, if a meaningful margin is to be defined with regard to the allowable crosswind components whilst on the helideck. It is also important to establish the variation of main rotor lift with wind speed and upwash component for other helicopter types. A helicopter with a wider track and/or a lower CG may be similarly vulnerable if the Main Rotor lift at MPOG is only slightly higher that that of the Super Puma. The aerodynamic forces induced by crosswind components have been shown in this accident to be the most significant of the toppling moments applied to the helicopter. Whilst there are crosswind limits published for hovering flight, no such limits are available to flight crews whilst parked, rotors running. Therefore, these forces are also likely to be an important factor for helicopters operating on fixed installations, where constraints of parking heading and/or the use of flight controls to counter the effect of a crosswind may exist.

The following Safety Recommendation is therefore made:

> It is recommended that the CAA should require Operators conducting offshore operations to publish crosswind limitations for helicopters when operating to, and when positioned on, helidecks, incorporating these limits into their company Operations Manuals. (Safety Recommendation 2003-133)

Such a programme could logically form an extension to the MSI research and, in view of the demonstrated unreliability of analytical models, would most probably be best achieved by field trials.

2.4 Helicopter Operations

The flight to the West Navion on 10 November 2001 was a routine passenger flight to effect a ship's crew change, conducted in conditions that were demanding but within normal operating limits. The landing was carried out skilfully in the correct position on the helideck with the helicopter pointing about 4° right of the last reported prevailing wind direction. On landing the helicopter adopted a 2.5° roll attitude to the right due to the effects of the landing gear geometry and the normal procedure of landing with the parking brake applied. During the time that G-BKZE was on the deck of the West Navion the commander requested the latest deck pitch and roll figures. Having been passed values of +/- 1.2° in pitch and +/- 0.4° in roll he commented that his instruments clearly indicated more, with values of 2° either way in pitch and 1.5° either way in roll being quoted. The graphical traces in Appendix B, Figure 2 show the actual data recorded around the time of these communications. They show pitch attitude varying between + 0.4° and + 2.9°with roll attitude peaks of between + 1.5° and +3.5° to the right. Given that the helicopter oleos have an associated compliance, it is understandable that the actual helicopter roll attitude excursions would have been slightly more than those of the helideck on which G-BKZE was parked. Thus it can be seen that the helideck roll peak-to-peak excursions quoted by the West Navion were entirely consistent with the data recorded on the helicopter. With oleo compliance having a lesser effect in the forward and aft direction, the ship's pitch figures reported are also consistent with the data recorded.

The roll and pitch were discernible to the commander from the helicopter's Attitude Indicator (AI); however, the graduations on the AI are in 10° increments below 30° of bank and 2.5° would have appeared as a relatively insignificant angle. Moreover the helicopter would have immediately taken up the movement of the ship after landing and the indication to the pilot would have been an offset mean to the aircraft's rolling motion rather than simply 2.5° of right roll. This would have made the attitude more difficult to detect, and in any event the helicopter crew were accustomed to a slight roll attitude after landing. Until this accident, it had not appeared significant to the safe operation of the helicopter. Nevertheless, even allowing for these difficulties, the values the pilot reported were within 1° of those recorded by the CVFDR.

It is possible that even if the aircraft had landed with symmetrically deflected landing gear oleos, it would have served only to delay the accident since the ship continued to yaw to the right. Indeed, the consequences of the accident occurring slightly later, given that embarking passengers may have been involved, could have been much more serious. On the other hand, it could be argued that the additional time may have presented an opportunity for both the helicopter and ship's crew to have recognised the situation and take action to avoid the accident. It should be noted, however, that there are no procedures published, or training given, for an emergency takeoff in the event that a flight crew consider that a helicopter is in danger of toppling.

Nevertheless, the helicopter's 'static' roll attitude after landing of 2.5° was more than 10% of the way toward the static toppling roll attitude of 23°, thereby rendering it more vulnerable to other toppling forces.

The following Safety Recommendation is therefore made:

> It is recommended that the CAA require offshore operators to review their landing procedures such that, after landing on moving helidecks, the helicopter's roll attitude, relative to the helideck, is neutral. (Safety Recommendation 2003-134)

The accident to G-BKZE occurred approximately 12 minutes after landing on the West Navion's helideck. The commander, alone on the flight deck, was unaware that the ship's DP system had lost heading control five minutes after landing and that, as a result, the West Navion was yawing to the right. The compass and direction indicators would have been reflecting this movement, but the commander would not normally refer to these instruments, especially as he was preoccupied at that time with preparations for the return flight. Normal procedures require him to focus much of his attention outside the cockpit. No external visual cues, such as land or a stationary ship, were available and the windsock, which would have been indicating the change in the relative wind, was not within the commander's field of vision. The ship's crew on the bridge were unaware of the loss of heading until the DP system gave a warning, which was close to the time the helicopter toppled. The only other source of a possible alert to the developing situation was the helideck crew, some of who had noticed the change in wind direction. However, they were not aware of the significance of the wind change to the helicopter and, quite reasonably, did not think to warn the commander.

Even had the commander noticed the deviation in the ship's heading, there was no emergency procedure to follow to achieve an emergency takeoff. This shortcoming has been addressed since the accident and the UK offshore helicopter operators have published an emergency take-off procedure for inclusion in their Operations Manuals. Furthermore the MSI project is developing limits of operability for all offshore helicopters. This will include takeoff, landing and stationary limits and will take into account wind effects.

2.5 West Navion's Procedures

The cause of the West Navion's loss of heading control is outside the scope of this investigation and has been the subject of other investigations by the HSE and the vessel owners. These investigations have not determined whether it was a manual intervention or a software fault that caused the DP system to change from AUTOMATIC to MANUAL heading control. However, a number of preventative measures have been put in place including a loss of heading alarm independent of the DP system and switches requiring a 'double touch' for some control functions of the DP software.

Of more significance to this investigation was communication between the ship and the helicopter. The inability of the helicopter to communicate with the HLO, other than by hand signals, meant that all communications with the helicopter had to be made through the RO on the ship's bridge. The RO's normal source of data for providing the helicopter with pitch, roll and heave information was remote from his normal position and, on the day of the accident, it was unserviceable. The RO therefore had to rely on data taken from the DP system. Disadvantages of this source were that it was also at a distance and not easily viewed from the RO's normal position on the bridge and the fact that it was not routinely provided or calculated in the form required by CAP 437.

When the ship's crew received the warning of the DP system's position error, their primary concern was to proceed with the laid down procedure for dealing with the warning. There was only a 12 second delay between the DP out of position warning and the helicopter toppling over and it is likely that by the time the bridge crew had assimilated the warning it was too late to provide this information to the pilot and prevent the helicopter from toppling over. Nevertheless there was no appreciation on the bridge that the ship's loss of heading might cause a problem for the helicopter. It is important that vessel commanders and their crews are aware of the helicopter's sensitivities with regard to wind, ship's motion and any ship emergencies, and procedures for communicating these problems to the helicopter should be put in place. In response to this accident, the UKOOA has established a requirement for installations, MODU's and vessels to have a procedure to inform a helicopter on the helideck of any change in alert status or change in vessel motion. This response was generated before the results of the mathematical analysis of this accident had been completed and, therefore, before it became fully appreciated the important contribution that the relative wind had on the stability of the helicopter. Since a change in wind direction, caused possibly by a line squall or other meteorological feature, could have a similar effect on helicopters sitting on helidecks, it is important that any changes in the prevailing environmental conditions are also conveyed to the helicopter pilot.

The following Safety Recommendation is therefore made:

> It is recommended that UKOOA revise their Guidelines for the Management of Offshore Helideck Operations to include a requirement for significant changes in environmental conditions, particularly wind speed and relative wind direction, to be communicated the pilot of a helicopter when parked, with rotors turning, on a helideck. (Safety Recommendation 2003-135)

2.6 Incident Investigation

The accident on the 10 November 2001 had similarities to a loss of heading incident that occurred on the West Navion four weeks earlier on 12 October. The cause was undetermined. A report by the Dutyholder into the 10 November accident stated that:

> *'…(if) the DP incident is in any way a contributory cause in the air accident, then it is reasonable to suggest that preventative actions taken post 12 October to prevent the heading loss incident may have prevented the air accident.'*

There is of course no guarantee that additional effort expended in the investigation of the earlier incident would necessarily have identified the cause, or indeed that the potential impact on aircraft operations would even have been considered. Nevertheless, the 12 October incident must be regarded as a missed opportunity to have prevented the occurrence of the second event.

The following Safety Recommendation is therefore made:

> It is recommended that UKOOA should include in its Guidelines for the Management of Offshore Operations a requirement, that following an accident or incident (regardless of whether or not it involved a helicopter at the time) operators of vessels, Mobile Offshore Drilling Units (MODUs) and fixed installations should consider in their subsequent installation safety investigations the potential safety implications for helicopter operations on helidecks. (Safety Recommendation 2003-136)

3 CONCLUSIONS

(a) Findings

1. The helicopter had a valid Certificate of Airworthiness and had been maintained in accordance with appropriate procedures.

2. The mass and centre of gravity of the helicopter were within prescribed limits.

3. There was no evidence of any defect or malfunction in the helicopter that could have contributed to the accident.

4. The flight crew were properly licensed and qualified for the flight.

5. The flight crew were in compliance with flight duty time regulations.

6. The flight to the West Navion and helicopter operations on board the West Navion were conducted in accordance with the helicopter company's Operations Manual.

7. The wind conditions and the West Navion's motion were within the laid down AS332L operating limits.

8. Continuously logged data was not available for the motion of the vessel. However, a 'screen shot' taken from the Dynamic Positioning (DP) system console immediately after the accident provided some pertinent information.

9. The helicopter's CVFDR provided data for the duration of the flight and for the time on the helideck.

10. Upon landing, the helicopter adopted an average roll of 2.5° to the right, relative to the surface of the helideck.

11. About seven minutes after the helicopter landed, the West Navion's DP system reverted to manual yaw control and the ship's heading started to drift to the right. As the ship became increasingly beam to wind, it began to list to the right.

12 Some five minutes after the ship's heading started to drift, the DP system gave an 'out of position' warning

13 No person on the West Navion's bridge was aware of the ship's change of heading until the DP system gave an out of position warning.

14 The helicopter pilot was not aware of the ship's change of heading and was not informed of the ship's change of alert status.

15 The helicopter toppled over 12 seconds after the DP system warning after the ship had yawed through some 35° to the right.

16 The helicopter's main rotor blades struck the helideck and fragmented. Flying debris injured the co-pilot and damaged parts of the ships' superstructure. The helicopter was substantially damaged.

17 The ship's helideck crew responded rapidly and appropriately to the accident.

18 The seriously injured co-pilot was given prompt and effective first aid treatment by the West Navion's medically qualified crew member.

19 The commander experienced difficulty in making his escape from the helicopter due in part to fire-fighting foam entering the cockpit.

20 The ships crew experienced difficulty in finding a suitable location on the ship from where the rescue helicopter could safely winch the crew of G-BKZE aboard.

21 As far as could be determined whilst the helicopter was on deck, the West Navion's pitch and roll excursions remained within IVLL limits for the AS332L.

22 Mathematical analysis of the forces acting on the helicopter indicates that the most significant toppling moments were caused by the aerodynamic forces arising from the increasing lateral wind component to which the aircraft was subjected as the ship yawed to the right.

23 The IVLL limits for helicopter operations to moving helidecks are not scientifically derived, and do not take account of wind, rates of movement or accelerations.

24 The CAA is currently researching a system to measure helideck motion severity, which may result in a Motion Severity Index (MSI), and this will be used to replace the current IVLL limitations.

25 The main rotor thrust developed at MPOG represented a significant portion of the helicopter's weight and contributed to its de-stabilisation.

26 A similar DP system failure leading to loss of yaw control occurred on 10 October 2001.

(b) Causal factors

The following causal factors were identified:

1 Unknown to the crew on the bridge, the ship's Dynamic Positioning system reverted to manual heading control and the ship's heading began to drift to the right.

2 The increased lateral wind component to which the helicopter was consequently subjected, generated increasing aerodynamic forces to the right due to the change in the relative wind, and these forces provided the most significant toppling moments of all the forces acting on the helicopter.

3 The 'static' roll attitude of the helicopter adopted after landing, relative to the helideck, of 2.5° to the right, together with the lift force generated by the main rotor in the prevailing wind, the 1° list of the ship to the right at the time of the accident and the natural motion of the ship, contributed to the de-stabilisation of the helicopter.

4 The lack of procedures on the ship to transmit the change in the alert status to the crew of the helicopter, and of any specified procedure available to flight crews concerning action to be taken if control of the ship is lost or degraded whilst on the helideck, denied the pilot an appropriate course of action to ensure the safety of the helicopter.

4 Safety Recommendations

The following Safety Recommendations have been made:

4.1 **Safety Recommendation 2003-133:** It is recommended that the CAA should require Operators conducting offshore operations to publish crosswind limitations for helicopters when operating to, and when positioned on, helidecks, incorporating these limits into their company Operations Manuals.

4.2 **Safety recommendation 2003-134:** It is recommended that the CAA require offshore operators to review their landing procedures such that, after landing on moving helidecks, the helicopter's roll attitude, relative to the helideck, is neutral.

4.3 **Safety Recommendation 2003-135:** It is recommended that UKOOA revise their Guidelines for the Management of Offshore Helideck Operations to include a requirement for significant changes in environmental conditions, particularly wind speed and relative wind direction, to be communicated the pilot of a helicopter when parked, with rotors turning, on a helideck.

4.4 **Safety Recommendation 2003-136:** It is recommended that UKOOA should include in its Guidelines for the Management of Offshore Operations a requirement that, following an accident or incident (regardless of whether or not it involved a helicopter at the time), operators of vessels, Mobile Offshore Drilling Units (MODUs) and fixed installations should consider in their subsequent installation safety investigations the potential safety implications for helicopter operations on helidecks.

P T Claiden
Inspector of Air Accidents
Air Accidents Investigation Branch
Department for Transport
May 2004

Unless otherwise indicated, recommendations in this report are addressed to the regulatory authorities of the State having responsibility for the matters with which the recommendation is concerned. It is for those authorities to decide what action is taken. In the United Kingdom the responsible authority is the Civil Aviation Authority, CAA House, 45-49 Kingsway, London WC2B 6TE or the European Aviation Safety Agency, Office G-12 02/74, Rue de Genève 12, B-1049 Brussels, Belgium.