AS332L Super Puma, G-TIGB

AAIB Bulletin No: 8/2003	**Ref: EW/C2002/2/6**	**Category: 2.1**
Aircraft Type and Registration:	AS332L Super Puma, G-TIGB	
No & Type of Engines:	2 Turbomeca Makila 1A turboshaft engines	
Year of Manufacture:	1982	
Date & Time (UTC):	28 February 2002 at 1130 hrs	
Location:	70 nm northeast of Scatsa, Shetland Islands	
Type of Flight:	Public Transport	
Persons on Board:	Crew - 2	Passengers - 18
Injuries:	Crew - None	Passengers - None
Nature of Damage:	Damage to tail pylon and tail rotor blades	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	51 years	
Commander's Flying Experience:	11,100 hrs (of which 2,000 were on type)	
	Last 90 days - 130 hrs	
	Last 28 days - 45 hrs	
Information Source:	AAIB Field Investigation	

Synopsis

G-TIGB was returning from the Dunlin A Platform to Scatsta, in the Shetland Islands, when it encountered severe weather generated vortices associated with a waterspout. During the ensuing rapid destabilisation of the helicopter, the tips of the tail rotor blades contacted the tail pylon. Following a safe landing at Scatsta, damage to all five blades and the pylon was discovered.

History of the Flight

Super Puma G-TIGB, callsign 802, was operating from its base in Scatsta to the Dunlin A Offshore Platform located approximately 100 nm to the northeast. It departed Scatsta at 1010 hrs, with a crew of two pilots and sixteen passengers, and transited in VMC at 1,000 feet on the Marlin QNH with the commander as the handling pilot. The wind was generally from 010° at 30 kt, the visibility was good and there were isolated severe storms under which there was heavy precipitation of sleet and hail. No lightning was seen by either of the pilots. The crew used the aircraft weather radar to monitor the storms and achieve a safe track in the clear areas between them. Turbulence was light and the autopilot[1] was being used to maintain the altitude and selected heading.

[1] The term autopilot used in this report is the generic name for the Automatic Stabilisation Equipment (ASE) fitted to the helicopter. This system has two lanes, which operate in parallel, and each lane has three channels,

As the aircraft approached the East Shetland Basin, the crew observed a large storm approximately 5 nm to the west of the Cormorant A Platform (located 20 nm southwest of the Dunlin A) tracking slowly south, Figure 1. They avoided this by flying to the south and landed on the Dunlin A at 1106 hrs. The helicopter was landed into wind, which placed the storm directly behind them at a range of approximately 26 nm. Following some 11 minutes behind 802, also flying at 1,000 feet, was another company Super Puma, callsign 803, transiting to the Cormorant A Platform. This crew also observed the large storm to the west of their destination but, significantly, noticed a waterspout on its southern edge. They reported its presence to Brent Radar at 1102 hrs. The waterspout had not been observed by the crew of 802 but the transmission from 803 to Brent Radar was monitored and they informed Brent Radar that they "had it on the weather radar". Both 802 and 803 were on their respective platforms, rotors running, at the same time and, as neither aircraft required refuelling, they both departed for their return flights to Scatsa once their passengers had been boarded. The helicopters lifted from their respective platforms at approximately 1118 hrs and commenced their return transit flights to Scatsta.

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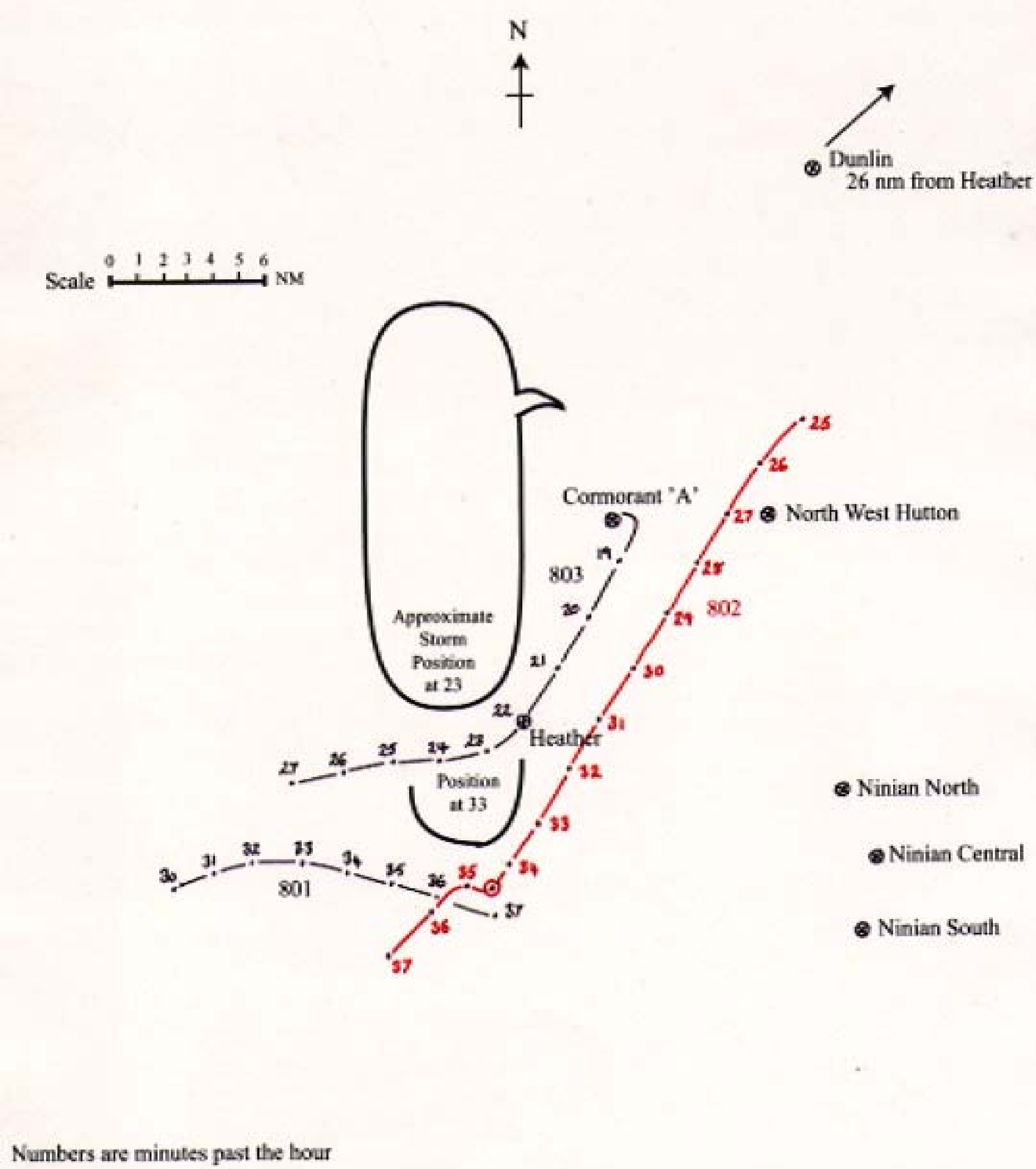
one each for pitch, roll and yaw. Both lanes, ie, all six channels, are required to be engaged for autopilot operation.



Radar Traces

The above radar traces show the return flight tracks of 802 and 803, as well as the outbound track of 801. Also shown is an approximate position of the storm.

Figure 1

The departure of 802 was uneventful and the helicopter became established in the cruise at 130 kt IAS (160 kt ground speed) on a south-westerly heading at the assigned altitude of 1,000 feet. The autopilot was engaged, altitude hold was selected on the flight director and the crew had their hands and feet clear of the controls.

Both 802 and 803 elected to route south of the Heather Platform around the southern edge of the storm and followed parallel south-westerly tracks, with 802 some 2.5 nm east of, and approximately 18 nm behind, 803. At the same time, a third company Super Puma, callsign 801, was transiting from Scatsa to the Brent Field at 1,000 feet on the Marlin QNH. Brent Radar observed that 802 was flying on a more southerly track to avoid the weather and asked if the crew would like to climb to 2,000 feet. They declined but stated that they might like to descend to 500 feet later. Having checked with this crew that they were happy with a 500 feet separation, ATC cleared 802 down to an altitude of 500 feet. The aircraft descended and maintained a heading of 217°M. At 1131 hrs, 802 was three miles to the south-south-west of the Heather Platform when the crew decided to turn slightly right towards Scatsta on a heading of 229° M.

The storm was now west of the Cormorant A Platform, with the southern edge of this weather north-west of the Heather Platform. The crew of 802 were advising ATC that they were clearing the storm and had resumed a course for Scatsta when the commander noticed a disturbance on the surface of the sea approximately 1 nm mile to his right. Later analysis of the on-board data recorder showed that, at about this time, the helicopter commenced a barely discernible climb of some 50 feet and that the barometric altitude increased by around 150 feet. Almost immediately, the helicopter violently pitched, rolled and yawed, with significant associated negative and positive g values being recorded. As the aircraft departed from normal flight, both pilots rapidly placed their hands and feet on the controls, the autopilot disengaged and the commander informed the co-pilot that he had control. Over the following 15 seconds the aircraft was brought under control but, during the encounter with this severe turbulence, the pilots recollected that the helicopter had climbed some 200 feet and yawed to the right through approximately 90°, with a large reduction in IAS.

In order to check the aircraft, the commander flew with a reduced collective pitch setting and found that it responded normally to control inputs, with no abnormal noise or vibration being present. He spoke to the passengers on the public address system to explain what had occurred and to reassure them that the aircraft was in a safe condition to continue to their planned destination of Scatsta. He then alerted the crew of 801 of the severe turbulence and suggested routing well south to avoid the area. After the commander handed control back to the co-pilot, he informed Brent Radar that they had encountered severe turbulence in the area of the storm. It was his opinion that this was possibly associated with the waterspout observed by the crew of 803 and that a warning should be broadcast to other aircraft. Subsequently, he called ahead to request that a company representative meet the aircraft in case any of the passengers had been traumatised by the encounter with this turbulence. From a later communication with Scatsta, however, it transpired that they were unaware of the turbulence encounter and that the request for the aircraft to be met had not been received. On arrival at Scatsta, the crew performed a running landing. After the passengers had disembarked, the inbound crew handed the helicopter to another crew who then taxied it to the north apron where it was shut down the in readiness for inspection by maintenance personnel. It was at this point that damage to all five tail rotor blades and the tail pylon was discovered.

Weather

At the time of the encounter, the weather in the area to the west of the East Shetland Basin was a wind from the north of some 30 kt, with isolated Cumulonimbus (CB) storm clouds. Beneath these clouds there was precipitation of rain, snow and hail but the visibility between the showers was good. A large storm, positioned to the west of the Cormorant Platform, was estimated in size as some 10 miles from north to south and three miles wide. The commander of helicopter 803, who reported the waterspout, described the precipitation below the associated cloud as very heavy and dark, and that the waterspout itself was located on the southeastern edge of this storm. Whilst this waterspout had been clearly visible rising from the surface of the sea, it did not reach the base of the cloud. The crew of 802 recollected that their weather radar showed this storm to be very active, with a 'hook' feature on its eastern edge. Another storm, located immediately to the southwest, was less intense but stretched away to the south for some distance. Although in VMC, the weather radar was being used to monitor the movement of the storms so that a safe route could be planned to avoid them, and this was visually confirmed. There was a clear and distinct gap of approximately five nm between these two storms, which were drifting in a southerly direction, and blue sky was visible between them. It was this gap that all three helicopters were using to transit between the platforms and their shore base.

Waterspout formation

The tornado formation process has been a subject of study for nearly a century. Today, it is widely accepted that tornados form within supercell thunderstorms where horizontal vorticity is tilted into the vertical and stretched by strong updrafts. These supercell tornados can be a persistent feature, the visible funnel of which can remain on the ground for an hour or more. The surface vortex is a product of 'spin down' from an intense mesocyclone (middle sized cyclone as opposed to those on a synoptic scale) which forms within the parent cell. These mesocyclones are typically large and intense with average diameters of 3-9 km and with differential velocities ranging from 40-80 m/s. This intense, larger scale rotation occurs about mid-level within the parent cell and usually extends through a deep layer, making them easily detectable by Doppler Radar.

By contrast, but with the exception of possible strong tornadic waterspouts associated with well-organized marine supercells, waterspouts are generally rapidly developing and dissipating features, often lasting less than 20 minutes. Most waterspouts have been observed to form along mesoscale surface air mass convergence boundaries. These boundaries are usually the product of other convective activity nearby, or differential heating, but have also been observed to form and persist offshore in the absence of convection or apparent strong surface temperature differences. The horizontal wind shear and low level air mass convergence along these boundaries act to produce cumulus congestus (heaped cumulus cloud) lines, and subsequent showers and thunderstorms. These cells occasionally spawn waterspouts.

It is believed that vortices are produced at or near the surface, along the shear axis of these boundaries. As these vortices propagate along the shear axis, they occasionally become co-located vertically with cumulus cells. Comparison made between reported waterspouts and co-incident Doppler Weather Surveillance Radar has indicated that waterspouts are produced as such cells are increasing in intensity. The updrafts stretch the surface vortex, producing a spout, Figure 2a. Even though it might not be visible, a continous vortex extends from cloudbase to the surface. As the wind increases to around 35 kt, sea spray becomes visible in a circular pattern around the surface vortex, and a funnel is usually seen at least part of the way down from the cloud base towards the centre of the surface ring of spray. As it develops, a visible funnel comprised of water droplets may extend all the way between the base of the cloud and the surface. Waterspouts may produce winds of 40 kt or more.

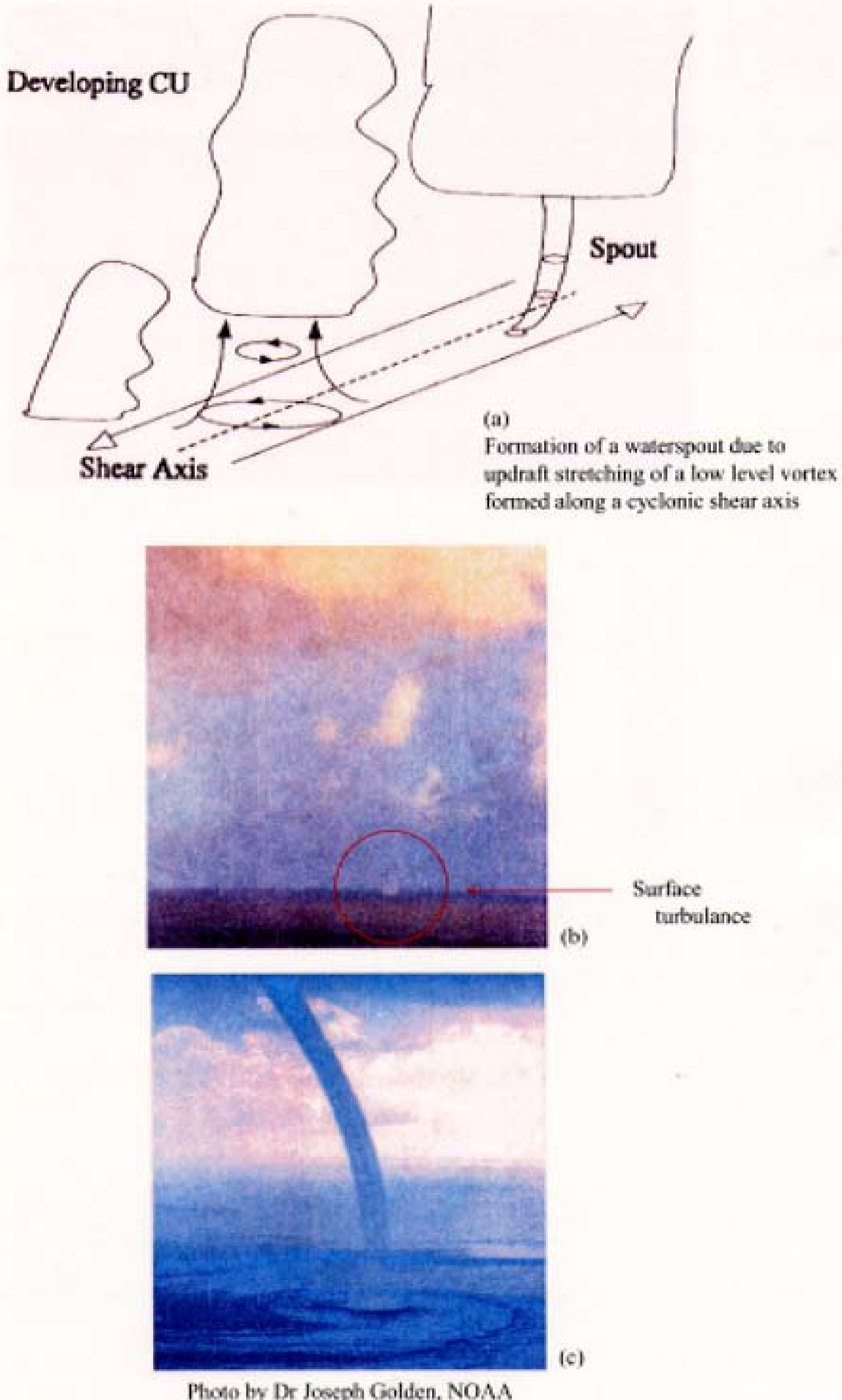


Figure 2

Figure 2b is a photograph of a waterspout related disturbance on the surface of the sea, before becoming fully developed, and is included as it is considered to be similar to that described by the crew of 802.

Figure 2c is a photograph of a developed waterspout and illustrates a large area of disturbed water, caused by the mass of rotating air that will be present around a waterspout. In addition, it shows that a waterspout is unlikely to be a truly vertical feature.

Related operational requirements.

The company Operations Manual contained a chapter with comprehensive guidance on *'Adverse and Potentially Hazardous Atmospheric Conditions'.* This chapter, which is sub-divided, provides guidance on '*Operating in the Vicinity of Storm Cells', 'Recommended Practices for Operations Near Areas of Thunderstorm Activity*' and a '*Table*' providing advice *on 'The Use of Weather Radar for Thunderstorm Detection*'. Within this table, the following extract is re-produced under the heading *'Echo Characteristics, Shape'. 'Avoid by 10 miles echoes with hooks, fingers, scalloped edges or other protrusions'.*

The crew thought that the 'hook' was an indication of the position of the reported waterspout and adjusted their track to avoid it. They were not able to recollect its distance from the incident location but, being some distance away, it was unlikely to be associated with the waterspout and the 'hook' itself was probably an indication of the severity of the storm. In consultation with the CAA, the Operating Company have taken the view that, whilst it is recognised that waterspouts are a significant weather phenomenon, they are one of many that can be associated with the types of weather conditions described in the Company Operations Manual. Compliance with this weather avoidance guidance should ensure that waterspouts are not encountered. Waterspouts, however, are not specifically mentioned in the guidance material.

Flight Recorders

The aircraft was equipped with a Combined Voice and Flight Data Recorder (CVFDR) and an Integrated Health and Usage Monitoring System (IHUMS). The CVFDR was a recycling recorder that maintained a record of the most recent five hours of data and one hour of audio information. The subject helicopter was one of six assigned to the Helicopter Operational Monitoring Programme (HOMP) trial for which it had been fitted with a solid state PCMCIA memory card that recorded the same data set as the CVFDR.

The IHUMS was downloaded after the event but no anomalies were observed in the data. As has been described in a previous AAIB report (2/98 - incident to G-PUMH on 27 September 1995), the IHUMS takes data snapshots during various phases of flight and additional snapshots are scheduled on an elapsed time basis. This includes snapshots of rotor track and balance (RTB) together with engine and gearbox vibration parameters. RTB data is taken once per flight phase whilst the engine and gearbox data is sampled approximately once per hour during the cruise. No snapshots of relevance were scheduled for the time between the onset of the event and aircraft shutdown. Data from the HOMP recording was downloaded expediently by the operator and was made available to the AAIB investigation team upon their arrival at Scatsta. The CVFDR was replayed by the AAIB, to recover the audio information, and also to back up the data obtained from the HOMP system. All data and audio recordings were of excellent quality and covered the entire period of the incident flight.

Recorded data, Figure 3; turbulence encounter

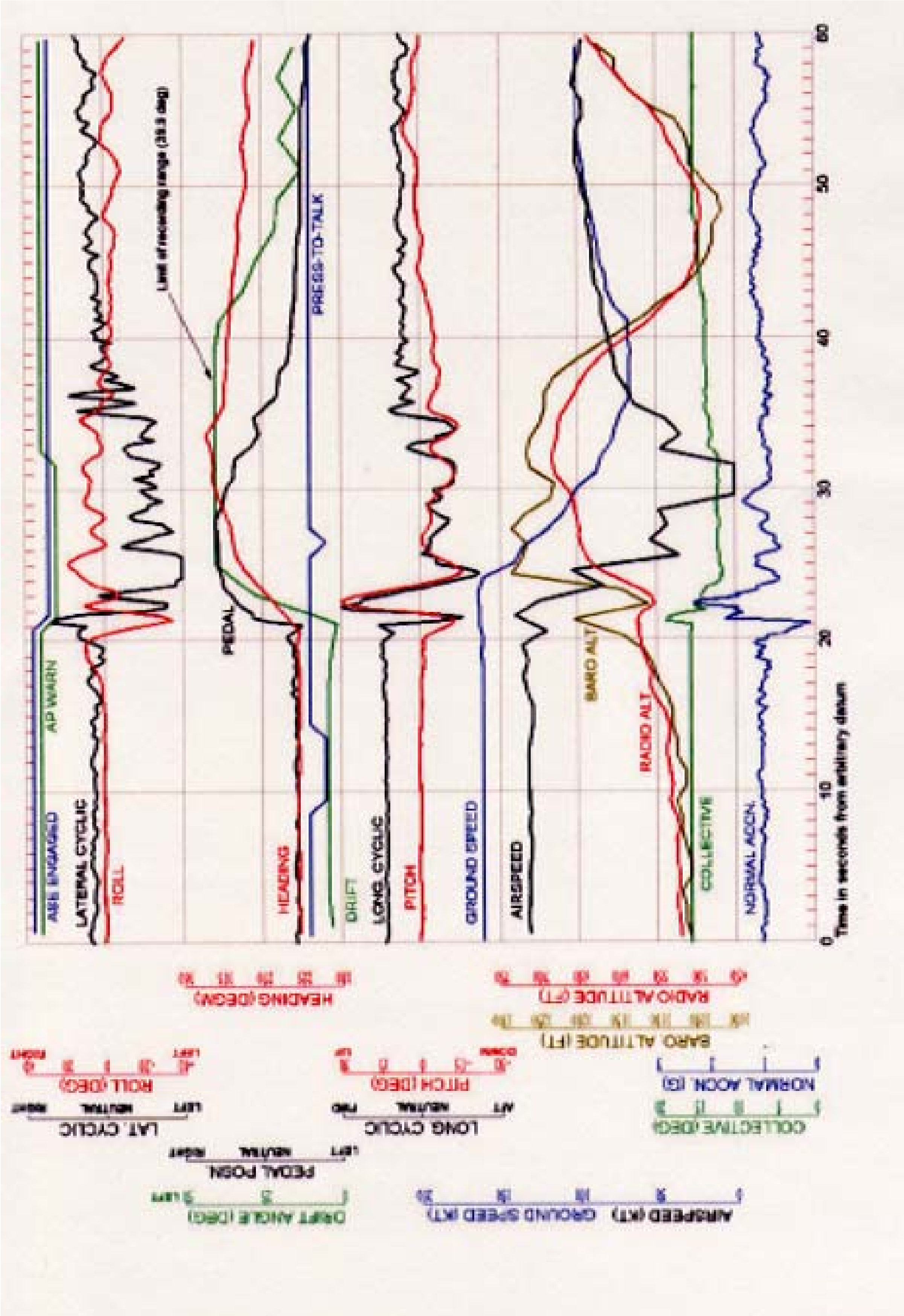


Figure 3

The onset of the event, at position N 60° 57.4' E 000° 54.2', was marked by a gradual increase in both recorded radio height and pressure altitude. The pressure altitude increased at a faster rate than radio altitude and indicated that atmospheric pressure was reducing at that point. Towards the end of this increase, the helicopter rolled to 9.5° right and, in just under 2 seconds, to 34° left whilst pitching 13.4° nose down and yawing to the right. All three channels of both autopilot lanes disconnected, the autopilot FAULT amber caption illuminated for 10 seconds as a result, and normal acceleration values varied from 1g to zero and up to 1.7g over the same period. Right and aft cyclic was applied together with right yaw pedal. Over a period of 0.75 seconds, the helicopter's heading increased through 250°M (21° to the right of the original heading) and, as it continued to yaw right and roll to 10° right, the pitch attitude increased to 29.8° nose up. The helicopter began to climb and a maximum normal

Over the following three seconds, its heading increased through 300°M and it continued to climb and yaw to the right. Pitch attitude then reduced to a minimum of 15.9° nose down, before being corrected with aft cyclic, whilst the roll attitude varied from 8° left to 18° right, each excursion being opposed by lateral cyclic inputs. The collective pitch was lowered from 15° to 12°, and right yaw pedal was maintained. With this right yaw input applied, the corrective lateral cyclic movements ranged from full left to half of full left travel. Also, during this time, recorded airspeed values fluctuated between 123 kt and 83 kt and the ground speed reduced by 20 kt to 120 kt. (Airspeed values recorded would have been affected significantly by pitot / static system errors, as aircraft drift[2] angles in excess of 39.9° were evident at that time. The maximum recording range capability of the CVFDR system for drift angle is +/-39.9° and this capability was exceeded during the upset).

Over a further period of eight seconds, the helicopter continued to yaw right, to a maximum heading of 333°M. Pitch attitude variations then reduced in amplitude, followed by those of roll attitude. Recorded airspeed values reduced to zero at the highest point of the climb (680 feet radio altitude) before beginning to increase as the aircraft pitched nose down. A gradual left turn was commenced in the descent, as airspeed began to increase, and progressively less left cyclic and less right yaw pedal was applied. Whilst accelerating through 75 kt airspeed, ground speed reached a minimum value of 66 kt and the drift angle began to reduce below 39.9°. It was also evident, from the differences between the recorded values of radio and barometric altitude, that the aircraft was leaving the area of reduced pressure that marked the onset of the event.

The flight traces shown in Figure 3 are repeated in Figure 4, but with selected snapshot representations of the helicopter's attitude during the encounter.

[2] Drift angles refers to the measured difference between magnetic track and magnetic heading. The figures quoted in this report include a measure of sideslip, and it is the sideslip angle that gives rise to pitot/static errors.

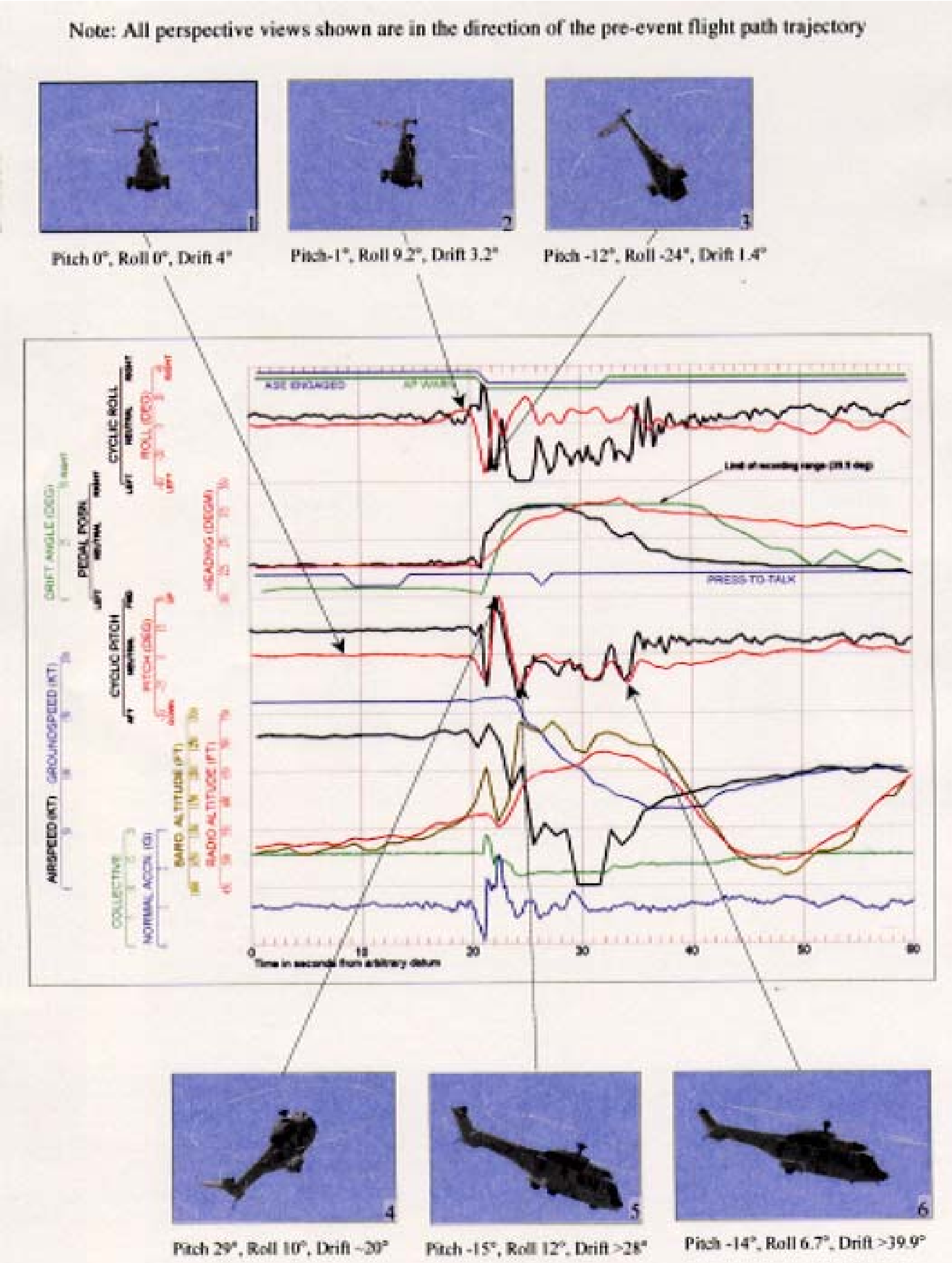


Figure 4

Recorded data, remainder of the flight

From a minimum of 500 feet (radio altitude) the aircraft climbed and levelled off, initially, at 800 feet and the autopilot was re-engaged. During the remainder of the flight, which was uneventful, the crew discussed the severity of the turbulence whilst the helicopter cruised at 1,000 feet amsl at 125 kt. They commented on the fact that, at the onset of the encounter, they had been flying in clear air, with no precipitation, and at a distance that they believed to be far enough away from the turbulent activity associated with the storm visible on their right.

Following an uneventful arrival at Scatsta, the passengers disembarked. With rotors still running, the two inbound crew members exchanged with a new crew, who then taxied the aircraft to the north apron. There the aircraft was shut down normally and the CVFDR recording terminated.

Aircraft maintenance information

The most recent maintenance was a 50 hour inspection carried out on 27 February 2002, ie, the day before the incident. This included inspections of engine and gearbox chip detectors and the tail rotor feathering hinges. The aircraft had not been carrying any deferred defects.

Tail rotor system description

Power is transmitted from the main gearbox to the tail rotor via tubular shafts and through two gearboxes. At 100% N_R the shaft speed is 4,888 RPM at the output of the main gearbox. The intermediate gearbox at the base of the pylon turns the drive through 40° and reduces its speed to 3,751 RPM. A further reduction to 1,279 RPM is made in the tail rotor gearbox, which also turns the drive through 90°. When viewed from the right hand side, the five bladed tail rotor rotates in a counter-clockwise direction and produces an anti-torque thrust in a yaw right sense.

Tail rotor blade pitch is controlled by a hydraulic servo unit, and is operated by movement of the pilots' yaw pedals via control rods, cables and quadrants. The actuating rod of the servo passes through the centre of the tail rotor drive shaft and is coupled to the pitch change spider, which in turn is connected to the individual blades via non-adjustable links.

Tail rotor blade description

The tail rotor blades are of composite construction, with the main structural member consisting of a D section leading edge spar. This spar is constructed from a continuously wound glass-fibre filament, or roving, that also includes the blade retention bushes. The skins are fabricated from carbon-fibre reinforced plastic (CFRP) and the internal voids are foam-filled. A thin titanium erosion shield is attached along the leading edge and around the blade tip.

The aircraft was initially certificated, in 1981, with the A1 standard of tail rotor blade. An A8 standard was developed in 1989, in order to improve impact resistance, and this introduced two span-wise webs: a CFRP one at the mid chord position, and a glass-fibre reinforced plastic (GRP) web at the approximate three-quarter chord point. A 'half' roving at the trailing edge was also introduced. On 19 January 1995 an accident to a Super Puma, registration G-TIGK, resulted from severe tail rotor blade damage following a lightning strike. (See Air Accidents Investigation Branch Report No 2/97). Improved electrical bonding was subsequently incorporated into the blade structure and this included extending the titanium erosion shield around the blade tip. This became the A9 standard and was introduced by Service Bulletin (SB) 01.00.59 issued in November 1999. The SB was subsequently mandated by a French Consigne de Navigabilité (Airworthiness Directive), No 2000-003-075(A), in January 2000. Thus, the blades on this aircraft were of the A9 standard. (An A10 standard is also available, which is identical to the A9, except for the addition of anti-ice heating elements). Cross-sections of the A1 and A9 standard blades are shown in Figure 5.

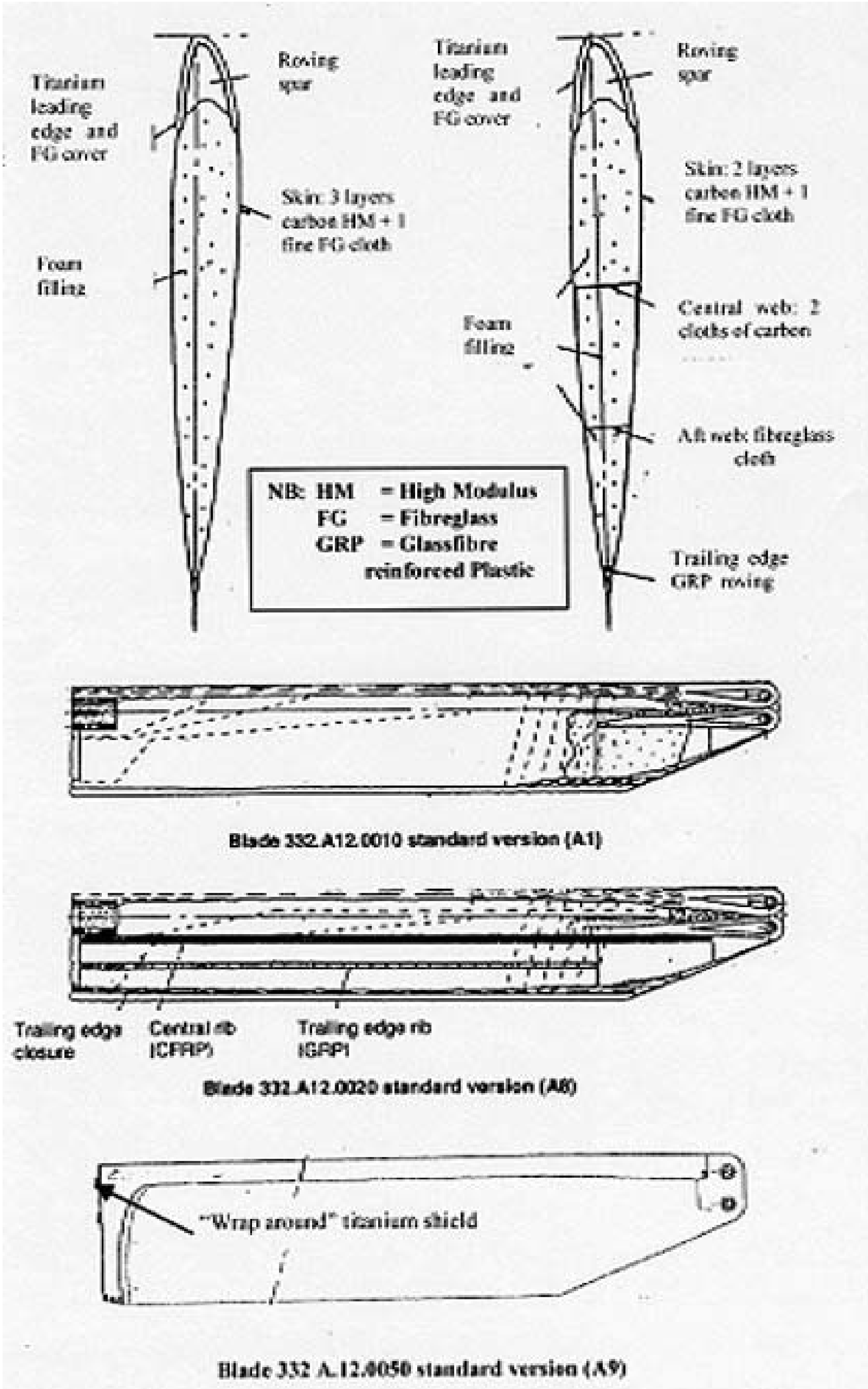


Figure 5 Construction details of three standards of tail rotor blade

Examination of the helicopter

It was apparent that all five tail rotor blades had contacted the pylon on its right side, towards its leading edge. This point corresponds to the thickest part of the aerodynamic profile of the structure and, consequently, this region of the pylon is in closest proximity to the tail rotor disk in its normal running position. Thus, contact was made by the upper, or suction surface, of the tail rotor blades at their tips. The pylon structure had been penetrated to a depth of around 25 mm, creating a gash approximately 150 mm in length. Most of this area of the pylon is constructed with a single thickness skin, with two light stringers attached to the internal surface; however, at the forward end is a doubler that covers a reinforcing angle at the edge of the tail rotor driveshaft decking. This angle had not been severed, although it had suffered severe distortion to the extent that a P-clip at the edge of the decking, which carries electrical cables from the tail rotor gearbox chip detector and IHUMS transducer, had been dislodged. However, the cables were intact, as was the driveshaft fairing. It was apparent that the relatively stiff structure in the region of the angle had been responsible for most of the damage sustained by the rotor blades.

A 'go/no-go' gauge was used on the tail rotor hub in order to check if the blade pitch range was within the maintenance manual limits. This was found to be the case. Thus, the possibility of excessive blade deflection resulting from over-pitching could be excluded as a cause of the tail rotor blades contacting the pylon. Whilst examining the hub it was observed that the flapping stops had suffered some crushing damage. The aircraft manufacturer later established that, despite the high aerodynamic loads to which the tail boom had been subjected, no misalignment or distortion had occurred as a result of the event.

The autopilot system was not investigated, as it was successfully re-engaged after the incident. Whilst a number of defects could arise which would result in a single channel dropping out, it was considered unlikely that all six would fail simultaneously. It was therefore concluded that the most probable reason for its disconnection was the inadvertent operation of the disconnect button on the cyclic control column as the crew initially attempted to regain control of the helicopter.

Examination of the tail rotor blades

Externally, the extent of the damage appeared to be similar for all five blades. Two of them had suffered chordwise cracks at approximately two thirds span, measured from their roots. A slight kink was evident in the leading edges of these blades. One blade had suffered delamination along much of its trailing edge, and all of the blades had small fragments of material removed from their trailing edges close to the tips. Details of typical damage, and the damage to the pylon, is presented in Figure 6.

View of right hand side of pylon showing damage

Typical contact damage

Outer surface of blade, showing chordwise skin fracture due to bending

FIGURE 6 Damage to Aircraft

Four of the blades were returned to the manufacturer for examination. The remaining blade, which was the one with delamination along its trailing edge, was examined by the QinetiQ Structures and Materials Centre at Farnborough. In view of the fact that complete disintegration of one or more blades would have resulted, at best, in a forced landing on water, the examination was directed towards establishing the degree of damage sustained by this blade at the time of contact with the pylon, and the extent of damage propagation during the remainder of the flight. In addition, comparisons were made with earlier blade standards.

It was determined that contact with the pylon had caused bending and twisting of this blade near the tip and that this had resulted in cracking of the skin and fracture of the CFRP web. Additionally, the impact and bending had promoted disbonding of the CFRP and GRP webs, as well as causing separation of the trailing edge skins. It was apparent that the two spanwise webs had conferred additional rigidity to the blade, compared with the A1 standard, and that this had limited the degree of bending which occurred on contact with the pylon. The webs had also helped to keep the two blade skins together, reducing the extent of disbonding of the foam core along the span of the blade. The presence of the titanium erosion shield around the blade tip also appeared to have helped significantly in holding the blade skins together. It was initially considered that once the damage had occurred, aerodynamic loads would have served to extend the damaged areas; this appeared to have been minimal and it was concluded that no further significant loss of material had occurred following the initial event. The evaluation of the tail rotor blade damage could only be qualitative; however, it was apparent that it was inherently stronger than earlier standards of blade. There had been no significant propagation of damage for the remainder of the flight following the encounter and this was, therefore, a strong endorsement of the measures taken to improve the blade, which displayed good impact performance and survivability.

Previous Occurrences

During the course of the investigation a number of similar occurrences were identified, all to helicopters in military service, where the tail rotor had contacted the tail pylon in flight. A brief summary is set out below:

1987 AS332M Far East, no information.

1991 AS332M1 Europe, sudden manoeuvre to avoid an obstacle during poor visibility.

1992 AS332L Display flight.

1998 AS332B Middle East, no information.

1998 AS332UL Europe, demonstration flight.

2001 AS332C1 Europe, military flight. Evasive action to avoid an obstacle at night.

Two more occurrences in 1992 and 1995, involving military AS330J helicopters, were also identified. Both occurred during display flying.

Simulation of the event

Data from the CVFDR was used to provide inputs to the helicopter manufacturer's in-house computer simulation model of an AS332L. This is known as HOST, and it was configured with the same weight and centre of gravity position that applied to G-TIGB at the time of the incident. The first stage of this simulation was to input the recorded lateral cyclic, longitudinal cyclic and yaw pedal control displacements and compare the simulation results of helicopter attitude with that recorded by the CVFDR. A sample of the results is shown in Figure 7a, where it can be seen that the simulation, not surprisingly, predicted a roll to the right whereas in reality there was a violent roll to the left. In each of the simulator evaluations, a 20 second section of data was used in which an arbitrary datum of time equal to zero was set approximately 11 seconds prior to the event.

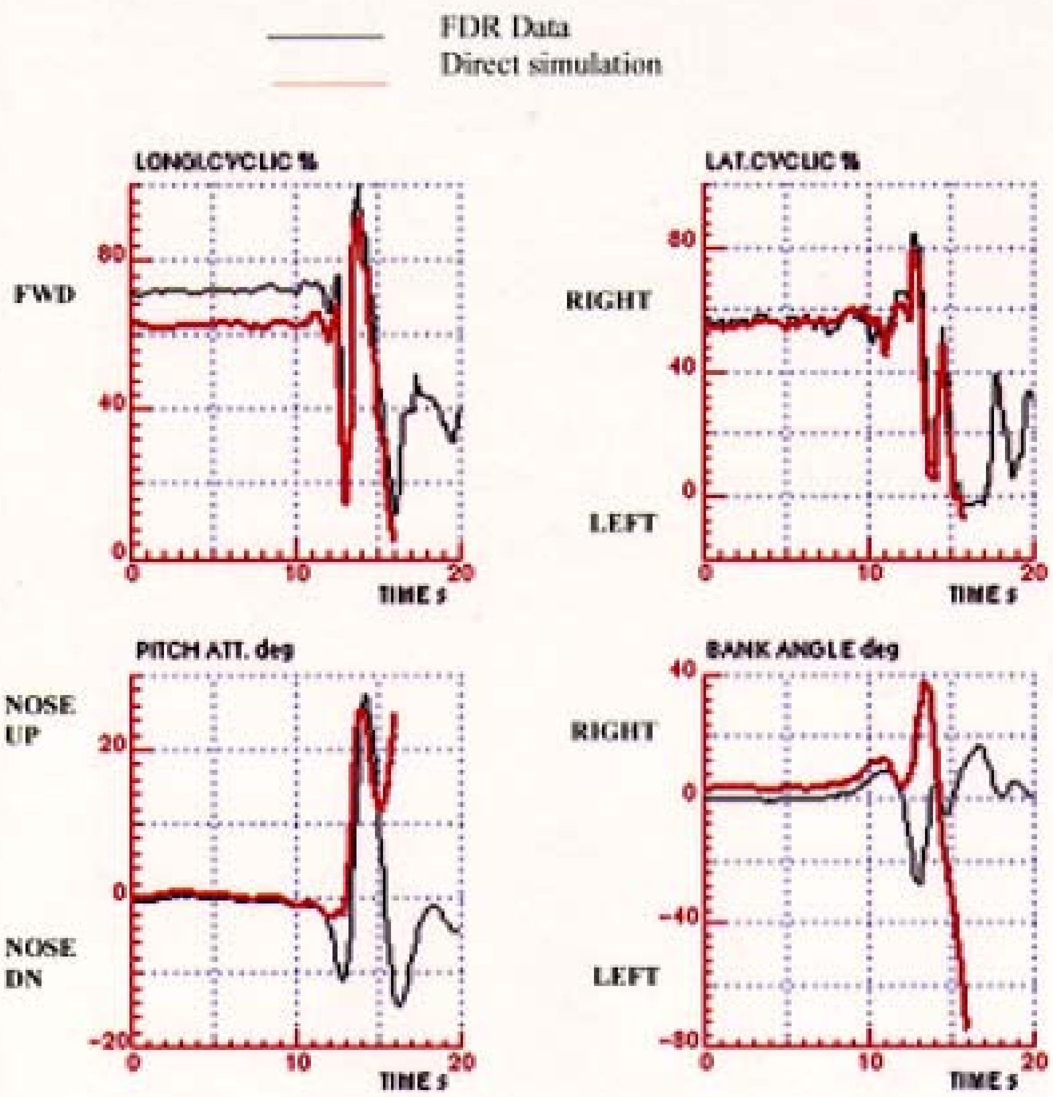


Figure 7a Direct simulation, showing how cyclic inputs provide poor comparison with FDR attitude

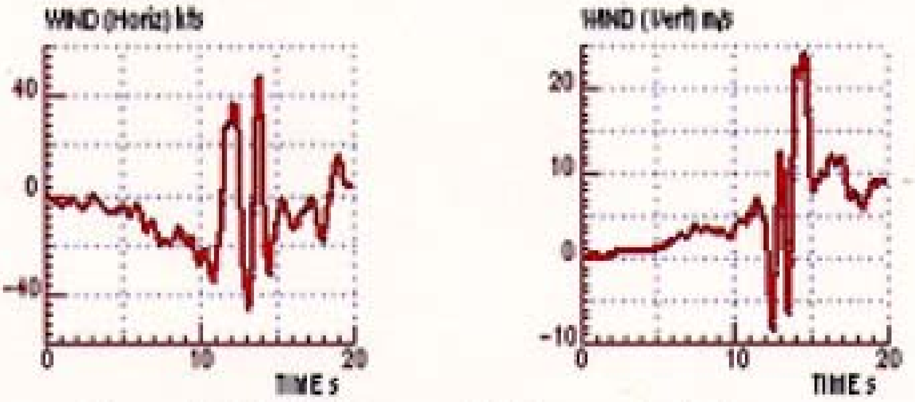


Figure 7b Derived gust, used in inverse simulation

Figure 7

The next stage was an inverse simulation, using the actual aircraft attitude data of pitch, bank angle and yaw as inputs, with the output being the calculated control positions and load factors, ie, accelerations in the longitudinal and lateral axes. Again, a poor match was demonstrated with the recorded data with a particularly large discrepancy being apparent in the lateral acceleration. Such a discrepancy could only be accounted for by a significant external disturbance of the helicopter and so additional inverse simulations were conducted in order to identify potential gust profiles that could result in the recorded aircraft attitudes and accelerations.

Any helicopter main rotor disc will react to a gust by tilting away from the gust direction; for example the phenomenon of 'flap back', which occurs when the aircraft transitions from the hover into forward flight, is well known. The G-TIGB incident was characterised by a left roll, nose down manoeuvre, indicating that the relative gust was on the right rear quarter of the aircraft. Thus, for the purposes of the additional simulations, a gust direction of 135° relative to the aircraft heading was assumed. The vertical and horizontal components of the likely gust were calculated using this figure; however, any variation in the direction of this gust would result in one component increasing with the other decreasing.

After a number of iterations, a gust profile was derived, Figure 7b, that resulted in a reasonable match for the calculated and observed aircraft attitudes, control inputs and accelerations. These are shown at Figure 8. This showed the magnitude of the gust variation in the horizontal plane, over the first two seconds of the event, to have been around +/- 24.6 m/s (40 kt). In the vertical plane, variations of -9 m/s (17.6 kt) to +24 m/s (46.8 kt) were experienced. These gust variations induced load factors in the fore and aft (x) axis of around - 0.52 g to + 0.654g, and - 0.36 g to + 1.06 g over the same period in the lateral (y) axis. These gradually reduced to normal values over the next 16 seconds.

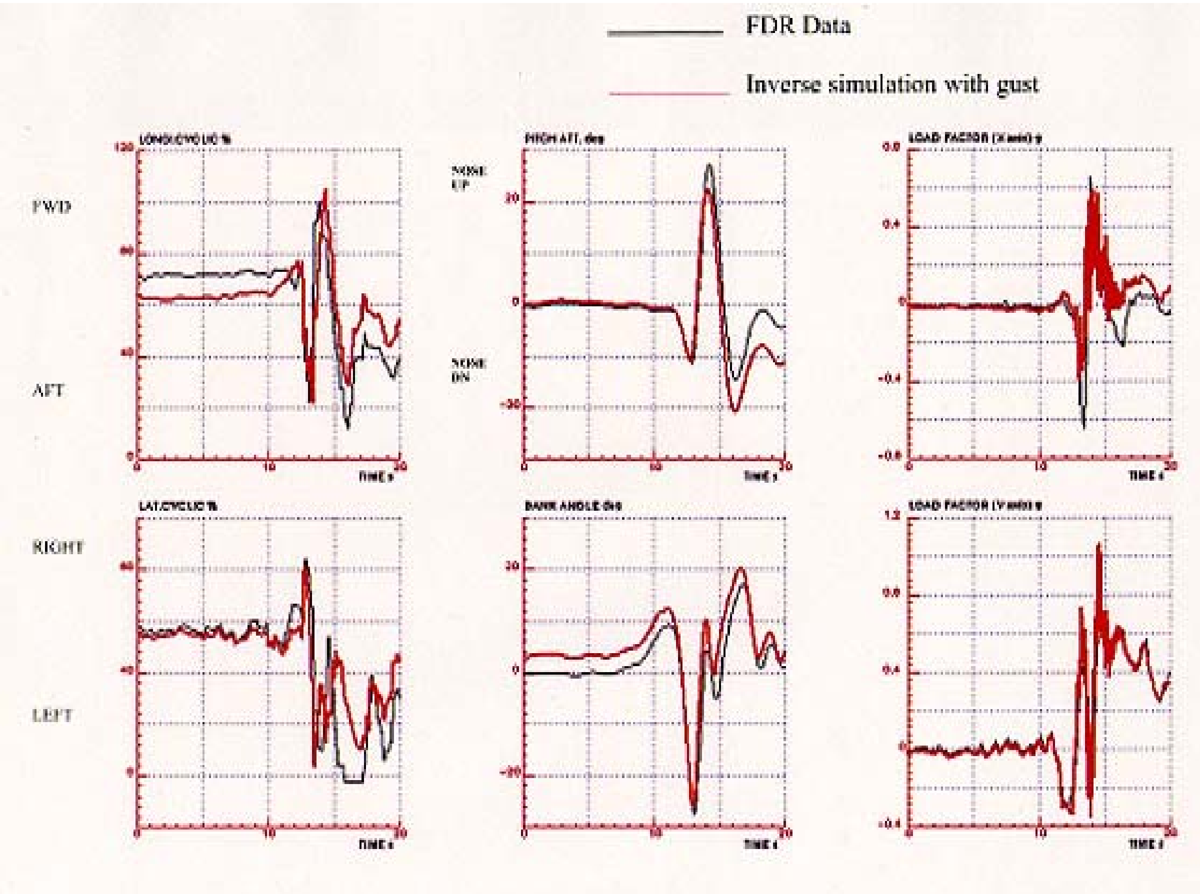


Figure 8 Comparison of FDR data and simulation results, using derived gust

The gust induced load factors were extreme and caused by gust variations well outside the Joint Aviation Authorities (JAR) maximum gust load requirements for helicopter certification. JAR 29.341 states that '*Each rotorcraft must be designed to withstand, at each critical airspeed including hovering, the loads resulting from vertical and horizontal gusts of 9.1 metres per second (30 ft/s)*'

The derived gust profile was applied to a mathematical model of the tail rotor, to which was added the yaw pedal input recorded by the CVFDR. The combined static and dynamic flapping angles were calculated for various blade positions around the tail rotor arc and these results are presented at Figure

9. It is apparent from this that contact occurred during the second 'pulse' of the gust, by which time considerable right yaw pedal had been applied. The manufacturer has stated that the pylon and tail rotor geometry is such that contact will occur when the flapping angle of the blades exceeds 11.5°. The manufacturer also stated that measurements had been taken on another AS332L, which was subjected to a turn with maximum right pedal deflection whilst in the hover. A balsa wood block attached to the pylon for the purpose of the test was shaved to within 50 mm of the pylon surface. Additional data from the manufacturer indicated that if the predicted maximum dynamic flapping angle of 5.5°, which occurs at the point of blade stall, is added to the 4° of static flapping to be expected at a typical cruise speed, then a total maximum flapping angle would be 9.5°. As this would give a clearance of 43 mm between the tail rotor blades and pylon, it thus appeared that the nature of the gust accounted for the additional minimum of 2° required for the blade tips to make contact with the pylon.

The manufacturer has pointed out that demonstration of adequate clearance between the tail rotor and pylon does not form part of the certification requirements. The limiting factor for rapid, full-scale yaw pedal deflection is the strength of the tail boom structural attachments.

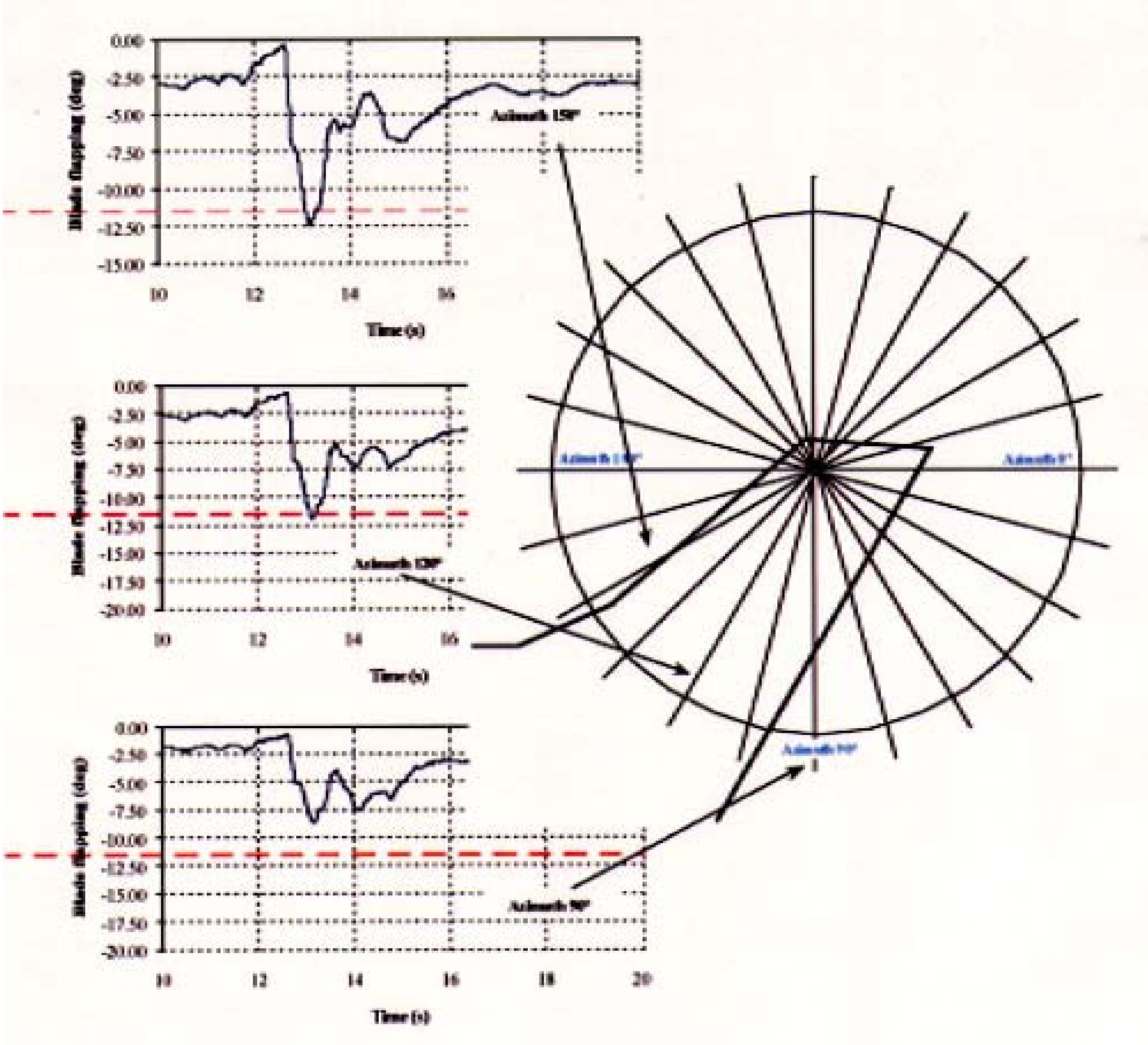


FIGURE 9 Tail rotor blade flapping angles due to gust and yaw pedal deflection (Contact occurs at 11.5°)

Analysis

The visible core of a waterspout represents the centre of a rapidly rotating mass of air (a vortex) and is relatively small when compared, for example, to that of a tornado. Although the actual disturbance on the surface of the water seen by the crew of 802 was not photographed, it was considered to have been similar to that shown in Figure 2b, ie, not clearly connected to the associated cloud. The fully developed waterspout, shown in Figure 2c, clearly indicates that a greatly extended area of atmospheric disturbance exists around the visible waterspout itself, and the possibility that the spout may not be a truly vertical feature. Thus, if a surface disturbance is the only manifestation of a waterspout, then the region of rotating air away from the surface could be significantly closer to the observer than it may seem. There is little doubt that G-TIGB was subjected to a violent upset from a gust, estimated to have been in the region of 40 kt, as a result of encountering significant atmospheric disturbance in the vicinity of a waterspout. The disturbance seen by the crew on the sea surface was approximately one nm distant at the time of the encounter. The probable gust was in the region of 40 kt (similar to the maximum reported wind speed associated with waterspouts). There was some doubt that the helicopter had flown in to the vortex associated with the observed disturbance, or possibly another one which had not been detected.

The crew were maintaining flight in VMC conditions, although the helicopter was being operated under IFR. The weather radar was being used by the crew to monitor the movement of the storms and to plan a route between them, which was confirmed by visual observation. They were aware of the 'hook' feature displayed by the radar on the eastern edge of the northern storm, and had planned to avoid this by choosing their route to pass between the storms. They also considered that the location of the hook might also be that of the reported waterspout. The guidance promulgated in the Operations Manual by the operator, recommended that such features should be avoided by at least 10 nm. Although the crew were unable to recollect how far away the 'hook' actually was at the time of the incident, they were certain that it was not directly associated with the disturbance on the surface, seen approximately one mile away. To them, the hook was an indication of the severity of the storm. The flight crew considered that remaining clear of cloud and transiting between the two large storm clouds, was a safe course of action and such avoidance of weather is a common necessity in the North Sea environment. Although the crew had been alerted to the presence of a waterspout by the crew of another helicopter, they only actually saw the disturbance just before the incident occurred. Initially, the helicopter rolled rapidly 34° to the left, due to the probable 40 kt gust from its right rear quarter (135° clockwise from the aircraft nose) and, at the same time, pitched 13.4° nose down. The autopilot tried to correct this departure but, as the pilots grasped their cyclic controls, one of them inadvertently pressed the disconnect button. It is probable that this initial left bank and nose down pitch would have been much greater without the positive control inputs from the commander, due to the limited rate of operation the autopilot.

The CVFDR data was used in an inverse simulation in order to calculate the likely gust profile that caused the recorded manoeuvres, taking into account the known control inputs. The manufacturer carried out an analysis of the data downloaded from the CVFDR, by using their type-specific computer model, to establish the helicopter's flight path which would have resulted from the control inputs made by the pilots. That information was then compared with the recorded flight path achieved by the aircraft, and the difference translated into accelerations along the three main axes. The strength, as well as direction, of the atmospheric disturbance or gust required to create the initial disturbance was then calculated. This reverse data analysis indicated that the aircraft probably experienced the type of short duration, but intense forces, which would occur by flying through the vortex around a waterspout. A microburst, for example, would probably have generated a more protracted destabilisation of the helicopter and then only from one direction

As with any mathematical model, it is difficult to assess the degree of credibility that can be accorded to the simulation results, especially with cases such as the subject incident where the normal flight parameters have been exceeded. However, whilst some doubt must remain over the absolute values of the gust and its direction, it seems clear that velocities involved exceeded, by a significant margin, the current maximum values specified by the certification requirements.

Conclusions

The investigation concluded that the helicopter had encountered a waterspout during its transit from an offshore platform to its operating base at Scatsa. Evidence of a waterspout was not visible to the flight deck crew until they were abeam it, and then only to the commander on the right side of the aircraft as a significant disturbance on the surface of the sea. Whilst the crew had made every effort to avoid the bad weather, both laterally and vertically, the effects of a waterspout occurred within seconds of the commander sighting this surface disturbance. No immediate avoiding action appeared to be necessary, as the waterspout was displaced about one nautical mile to the right of the aircraft track, although it is possible that the helicopter may have been affected by a different, undetected, vortex. However, the strength of the turbulence encountered was such that the induced accelerations exceeded the certification requirements for the helicopter. The combination of the gust induced accelerations, and the large amount of right yaw pedal required to maintain control of the helicopter, caused the tips of all five tail rotor blades to contact the tail pylon. The A9 standard of tail rotor blade, compared to the earlier A1 standard, was considered to have contributed significantly to the helicopter's ability to continue flight after the blades sustained serious damage.