Bolkow BO 105DBS-4, G-DNLB

AAIB Bulletin No: 8/2003	**Ref: EW/C2002/05/07**	**Category: 2.2**
Aircraft Type and Registration:	Bolkow BO 105DBS-4, G-DNLB	
No & Type of Engines:	2 Allison 250-C20 turboshaft engines	
Year of Manufacture:	1992	
Date & Time (UTC):	24 May 2002 at 1020 hrs	
Location:	Brough of Birsay, Isle of Orkney	
Type of Flight:	External load transfer (aerial work)	
Persons on Board:	Crew - 1	Passengers - None
Injuries:	Crew - 1 (Fatal)	Passengers - None
Nature of Damage:	Aircraft destroyed	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	53 years	
Commander's Flying Experience:	12,399 hours (of which 5,000 were on type)	
	Last 90 days - 101 hours	
	Last 28 days - 35 hours	
Information Source:	AAIB Field Investigation	

Synopsis

The helicopter was carrying out external load lifting operations from the Brough of Birsay island lighthouse off the north-west coast of the Island of Orkney to a site some two miles away on the main island. The pilot was very experienced in carrying out external load lifting and had transported a number of loads that morning without incident. On the accident flight the load was seen to become unstable and contact the tail rotor resulting in total loss of tail rotor thrust. The helicopter was seen to descend rapidly in a spiral to the right and impact the sea. The pilot was fatally injured during the impact and the helicopter sank almost immediately. Recommendations are made concerning the guidance available to load constructors and enhancing a pilot's chances of surviving a tail rotor strike.

Factual Information

History of the flight

The helicopter had been positioned to Orkney, the day before the accident in order to carry out a number of flights including the carriage of external loads. During these operations a licensed aircraft maintenance engineer accompanied the helicopter in order to provide technical support and to assist with the external load operations, on this occasion from the ground.

Having spent a quiet night in a local hotel, close to where the load lifting operations were to take place, the engineer carried out the daily inspection of the helicopter which included a serviceability

check of the load hook which worked normally. After breakfast, the pilot and engineer met with four persons from a local building contractor and two representatives of the client at approximately 0810 hrs. The weather was good with a south-easterly wind of about 15 to 20 kt. The external load lifting task required 11 loads to be brought from the Brough to a drop point on the main island shoreline, which was approximately 2 nm from where the loads were to be uplifted. There were also four loads to be taken from the mainland to the island. It was agreed that the helicopter would lift three contractor's staff and one of the client's representatives to the Brough in two flights whilst the two other persons remained on the mainland to receive and despatch the loads.

After a participants' briefing and allocation of duties, the aircraft commenced flying at about 0830 hrs. Having deployed the four men to the island to carry out the final preparation of the loads and attach the lifting strops, the pilot and engineer flew to the client's base at Stromness. From there they undertook a short transit flight taking three passengers to Auskerry and then returned to Stromness and refuelled. The aircraft returned to the Brough of Birsay at approximately 0940 hrs and the engineer left the aircraft to supervise the load lifting operations.

Whilst the helicopter was absent on its journey to and from Auskerry, the building contractor's staff packed most of the cargo of building materials into lifting bags; the only limitation for load construction was that the maximum weight should not exceed 450 kg. The loads were checked and lifting strops attached by the client's representative who had received training in carrying out these duties from the aircraft operator. Due to the wind which had increased to about 30 kt, the client's representative in consultation with the aircraft engineer decided that three loads, two of which comprised wooden shed sections and a 'Portaloo' would not be taken. This was based on previous experience of those types of loads being unstable in strong, gusting wind conditions.

The client's representative at each location attached a two metre metal strop (the lower strop) to the load to be flown. When the aircraft was in a low hover, the representative either attached or detached the lower strop to the end of the swivel safety hook on the end of the upper strop attached to the helicopter. This process was successfully undertaken with a variety of loads, which were transported according to a list provided by the client. Witnesses described the operations as taking place normally with all loads appearing to fly in a stable condition, the aircraft taking only a few minutes to transit between the two operating sites.

Having returned to the Brough to lift the penultimate load, the aircraft was marshalled over the load by the maintenance engineer. The load consisted of two scaffolding frames bound together with wire and a number of 16 cm x 1 cm metal electrical conduit sections approximately two metres long tied across the scaffolding in two groups with wire wrapped around the items and twisted together to secure them. Figure 1 shows a replica load.

Figure 1 - Photograph of replica load

The load was attached to the upper strop by the clients' representative who had been trained as an HLO (Helicopter Landing Officer) but on this day was acting in the role of 'Hook on Person'. When he was clear of the rotors, the aircraft engineer who was acting as the Load Dispatcher and HLO marshalled the helicopter into a high hover. As the load cleared the ground it began to rotate slowly which was not unusual. When the load was sufficiently clear of the ground, the engineer signalled to the pilot that he was clear to depart. The aircraft transitioned into forward flight, gently accelerating and climbing to an estimated height of 400 feet. The load stopped spinning and began to trail normally beneath the helicopter swinging from side to side in a reasonably stable condition. The wind direction had remained at about 130° but the wind speed had increased in strength to between 30 and 35 kt. As the helicopter crossed the southern shoreline of the island, the load swung back and became unstable, swinging fore and aft as well as from side to side in a circular spinning motion which rapidly caused the load to contact the tail rotor. Witnesses described the load as exploding or breaking up with debris falling from the aircraft and the engineer saw what remained of the tail rotor blades had stopped. One witness thought he saw the remains of the load falling away from the helicopter shortly after the impact.

Helicopter's final manoeuvres

After the load struck the tail rotor, the helicopter turned rapidly to the right through approximately 90°, rolled right and pitched nose down. It appeared to pause with a yawing motion left and right before entering a descending turn to the right. The helicopter disappeared from the view of the persons by the lighthouse but according to witnesses on a boat and others on the mainland, the fuselage continued to rotate around the rotor head some two to five times until it reached a height of about 30 feet. At that point it dropped rapidly then rolled to one side before striking the water very heavily in a banked turn to the right, with a nose-high attitude. The aircraft sank after a few seconds. Two local fishing boats commenced an immediate search for occupants and informed the Coastguard by radio. The Coastguard immediately launched a lifeboat and a Search and Rescue helicopter.

Personnel information

The pilot successfully completed his Line Proficiency Check on 28 March 2002 which included the external load element of the assessment. On 2 May 2002 he completed both the Emergency and Safety Equipment and Pilot Proficiency Check. In summary, the pilot was properly qualified and experienced to conduct the flight.

Aircraft Information

The BO 105 is a twin turbine five seat helicopter with a hingeless main rotor, having four composite blades, together with a two-bladed composite tail rotor. The foam filled main blades utilise a unidirectional glass-fibre roving lamination, which forms a loop around each blade root and carries tensile loads. Diagonally layered GRP skin panels confer torsional stiffness.

The aircraft is controlled by mechanical linkages through a self-contained dual redundant hydraulic pack, powered from two independent pumps driven by the main rotor gearbox.

Engine speed selector levers are positioned above the pilot. They are set fully forward during normal flight when engine power is automatically controlled to maintain an appropriate rotor speed. They may be moved back to the IDLE position causing the engines to run at a low power setting, insufficient for normal flight. They may then each be further moved fully back (after depressing individual plungers) to enable them to reach the CUT-OFF position. This causes the relevant engine to run-down and stop. The IDLE and CUT-OFF positions are available for use on the ground and may be used in flight under certain emergency conditions.

G-DNLB was equipped with a load hook operated electrically by the pilot, utilising a release trigger on the collective control. An emergency release could be operated mechanically by way of a foot control. An adjustable external mirror was fitted enabling the pilot to observe the load whilst it was within certain arcs. A two metre long metal strop was attached by a metal ring at one end to the aircraft hook. A swivel safety hook was installed at the other end of the strop. It was intended that the strop would remain with the aircraft throughout the lifting operation. Each individual load incorporated another dedicated strop which, for lifting and transit, would be connected to the swivelling load hook.

Aircraft Operating Weight

The helicopter's weight at the time of the accident was calculated at 2,156 kg including the external load; this was below the maximum permitted take-off weight of 2,400 kg. Fuel onboard at the time of the accident was calculated at 256 kg, which was sufficient for at least one hour of flying which was more than enough to complete the external load lifting task and transit to Stromness to refuel.

Flight Recorders

Flight recorders were not required for this helicopter and none were fitted.

Wreckage and impact information

The wreckage was located on the sea bed at a depth of approximately 8 metres. The pilot's body was secured in the right front seat. He was removed by divers shortly after the accident and prior to the arrival of the AAIB Inspectors. Underwater video photography was then carried out in order to assess the condition of the helicopter.

The resulting video images were studied. The wreckage distribution on the sea bed together with the degree of damage and break-up were noted. It was observed that the bulk of the aircraft, though severely damaged, was relatively complete but there was nothing connected to the helicopter's hook; both strops and the external load were missing. Locally the sea bed was covered with a dense growth of kelp with fronds up to 6 feet high; the length and density of kelp in the area made searching for the missing items impractical.

The wreckage was recovered from the accident site under AAIB supervision and, along with other items recovered during the initial search, transported to the AAIB's facility near Farnborough in Hampshire.

Detailed Aircraft Examination

It was confirmed that the structure was damaged in a way consistent with the aircraft descending rapidly backwards, parallel to its longitudinal axis, into the water. The two tail rotor blades, which were among the items recovered from the water before the AAIB arrival, had separated close to their roots in a manner consistent with having struck a firm object, rather than as a result of the water impact. All of the other items that had separated from the main wreckage were assessed to have done so as a result of water impact, on collision with the sea bed, or during the salvage.

The mechanical flying control system was examined and all components were found to be correctly connected except in areas where failures had occurred, which corresponded to other local structural damage. In all cases the failures were consistent with the expected effects of impact forces.

The dual hydraulic pack was removed from the aircraft complete with the two hydraulic pumps and the pressure hoses connecting each pump to the relevant hydraulic system. The pack and the two pumps were then installed on a dedicated rig normally used for functional testing of such systems after overhaul. All mechanical, electrical and hydraulic functions specified in the helicopter manufacturer's post-overhaul test schedule were carried out in the presence of an AAIB Inspector and all these systems performed according to specification.

The engine speed selector levers, together with their connections to the engines, were visually examined. Both levers were found to be at, or close to, the rear limit of their travel, suggesting they were in either the IDLE or the CUT OFF position. The nature of their design, coupled with the features of the impact, made it possible that some movement had taken place during the impact or salvage. It was considered improbable, however, that both would have moved the full distance from the normal flight position to the IDLE or CUT OFF positions as a result of the impact. Examination of the underwater video confirmed that the selector levers had not moved significantly between the arrival of the aircraft on the sea bed and the subsequent examination at Farnborough.

The engines were examined before their removal from the aircraft. They were then dismantled under AAIB supervision. It was judged that at the time of water impact, both engines were either not operating or were operating at low power. One engine had positive evidence that at the time of impact or very shortly beforehand, it had been functioning. There was no evidence of pre-impact mechanical failure in either unit.

The main rotor gearbox was examined externally and internally using an optical boroscope. No evidence was found of pre-impact failure.

Estimation of main rotor speed at water impact

The opinion of the helicopter manufacturer was sought in order to try and establish the main rotor RPM (RRPM) when the blades contacted the surface of the water. This assessment was carried out using notes and photographs supplied by the AAIB. The four main rotor blades were colour coded yellow, green, blue and red, and were always fitted in that order. In the manufacturer's opinion, the yellow blade on G-DNLB was the first blade to impact the water and had broken cleanly at the blade root where it entered the blade grip. The green blade had a lower energy failure as the RRPM reduced; again the failure was at the root but the fibre rovings gave a more fibrous appearance to the failure. The blue and red blades had failed outboard of the root. The manufacturer stated that this effect was caused by the blade flapping upwards and then twisting up at the leading edge of the tip. This failure mode caused the upper surface of the relevant blade to be shed.

A comparison was made of the main rotor blade failures on another BO 105 helicopter, which had been flown inadvertently into the sea with the RRPM at a normal setting of 100%. The first two blades broke at the root in the same 'clean' manner as the yellow blade on G-DNLB. The third blade failed in the same manner as the green blade and the fourth blade failed in the same manner as the blue blade. From this comparison, the manufacturer concluded that the RRPM of G-DNLB were less than 100%. The actual RRPM were-estimated at approximately 80 to 90%.

A re-assessment of the blade damage was carried out by the AAIB in the light of the helicopter manufacturer's opinion. It was noted that the actual root damage to the yellow blade differed from that assumed in their analysis as a consequence of some post-accident damage incurred during salvage and transport, rather than being an impact feature. The manufacturer made reference to 'broom-strawing' at the blade root; this referred to the way in which exposed fibre rovings projected from the grip on the green blade. The extent of this effect on the root end of the separated yellow blade was not clear in the photographs supplied, since the salvage and transport damage was only evident on close examination of the blade stump and the inboard end of the separated section.

It was also noted, however, that a fragment of the missing green blade was among the recovered items. When viewed in conjunction with the other blades, it was evident that the yellow blade was the only one to have broken off at the root without sustaining damage outboard. It was also clear that de-lamination had occurred on the remaining three blades, indicating that a considerable RRPM drop had occurred after the first (yellow) blade hit the water. Utilising the manufacturer's theory, this evidence confirmed that low RRPM were present at water impact.

Medical

Following a post mortem examination of the pilot, there was no evidence of any natural disease, alcohol, drugs or toxic substance which may have caused or contributed to the accident. The accident was considered to be non-survivable due to multiple injuries consistent with sudden deceleration as the helicopter hit the sea tail-first.

Tests and Research

External load evaluation

The external load being carried at the time of the accident was not recovered. The persons who had constructed the original load assembled an identical load, (as shown in at Figure 1). The scaffolding sections were attached to the end of the lower wire strop with canvas straps joined at a swivel connector. The total distance from the load hook connection to the bottom of the load was 6.95 metres. The total width of the load was 2.4 metres and it weighed 68 kg.

The replica load was taken to the Ministry of Defence (MOD) Joint Air Transport Evaluation Unit (JATEU) at Brize Norton in Oxfordshire. The role of JATEU is to assess loads, which may be required to be flown beneath MOD helicopters and stipulate the method of carriage. Their assessment of the replica load was that it would not be flown as an external load beneath a military helicopter due to the flat profile and lack of mass, which in combination, would cause the load to be highly unstable. If for operational reasons it was imperative to transport the scaffolding sections and electrical conduit, it would probably have been carried as internal freight. If it was not possible to carry it as internal freight, the items would either have been placed in a net with some heavy ballast or the scaffolding sections would have been suspended from each corner and ballast placed on the platform made by the load to give it stability. JATEU considered that the load as prepared would not only be unstable both longitudinally and laterally, but also tend to twist around the swivels.

A static assessment of the replica load when attached to the aircraft load hook and then laid out to the rear as if trailing behind the helicopter, showed that when trailing, the load could be directly below the tail rotor.

A flight evaluation of the replica load was carried out using an identical BO 105 helicopter. A 45 gallon container filled with water was suspended in a net from a 16 metre strop attached to the aircraft load hook with a swivel connector. This load provided a safety distance between the replica load and the helicopter. A load hook was attached to the bottom of the net and from this was suspended the replica load. The weather conditions were good with a surface wind of 15 kt gusting to 22 kt. The combination of loads was then flown at speeds up to 65 kt with gentle acceleration through the speed range. An uncommanded jettison of the load occurred at 65 kt, which caused the load to disintegrate as it struck the ground.

Prior to the jettison, three runs were made initially with the safety distance load alone and then two runs with the replica load attached to it. The first run demonstrated that the safety distance load was stable up to the 60 kt flown with only small gentle swings in the lateral and fore and aft axis. With the replica load attached, there was a small degree of interaction between the two loads. When the safety load swung one way, the replica load moved in the opposite direction; this only happened in the low speed range up to 20 kt. A more significant effect was that when the helicopter was accelerated, the safety load tended to act as a damper reducing the acceleration and resultant swing of the replica load. As the load combination was accelerated, both loads swung back, the lighter replica load more than the safety load. The replica load also described a circular motion with the scaffolding

sections slowly spinning around the swivel attachment. As speed was increased up to 65 kt, the motion became more exaggerated describing a larger arc but with the spin rate of the load remaining the same.

Additional research

Whilst the witnesses were consistent when describing the initial flight path of the helicopter following the loss of the tail rotor blades, there were differences in the number of orbits the aircraft was thought to have made before impacting the sea. In order to try and identify the difficulties encountered by the pilot and establish from the evidence his most likely actions, four main areas of work were undertaken:

a. Reviewing the recently completed comprehensive Civil Aviation Authority/Ministry of Defence commissioned research work on tail rotor failures.

b. Reviewing 21 previous tail rotor related accident reports provided by the aircraft manufacturer.

c. Investigating the flight characteristics of the BO 105 following the loss of the tail rotor using the helicopter manufacturer's fixed base engineering simulator and BO 105 procedure trainer.

d. A similar BO 105 was also flown to establish the height needed to accelerate the helicopter to the 60 kt requirement stated in the emergency check list, having lowered the collective lever fully but without retarding the engine speed select levers (SSL).

Review of previous accidents

The accident reports contained a cross section of failures including tail rotor drive shaft, gearbox and rotor blades, in the cruise at medium altitude, at low speed and at low height. When reviewing these reports, the common factors were how rapidly the helicopters yawed and rolled to the right accompanied by a large nose down pitching moment. The helicopters had also continued slow orbits to the right despite their collective levers being fully lowered. Attempts to raise the collective or reduce air speed caused the helicopters to increase their yaw to the right with a loss of airspeed necessitating immediate lowering of the collective. In only two accidents were both engines shut down; in the remainder the helicopter rotated to the right rapidly. When the collective lever was raised, even the application of maximum cyclic deflections to try and maintain the aircraft attitude level seemed to have little effect.

One pilot reported that in trying to control the helicopter, he was unable to remove his left hand from the collective lever in order to shut down the engines using the SSLs located at the forward end of the overhead console.

The most descriptive report was from a pilot who suffered a loss of tail rotor thrust in the cruise at 100 kt and a height of 2,000 feet above the sea. Once established in autorotation, any reduction in airspeed below approximately 80 kt brought an increased yaw to the right but maintaining the high airspeed created a very high rate of descent. Whilst the engine SSLs were brought back to IDLE on that occasion, when the helicopter was flared hard at approximately 50 to 75 feet above the surface it decelerated rapidly but the aircraft began to yaw to the right. At about 25 feet height the pilot raised the collective to check the rate of descent but the yaw to the right increased with the nose pitching down and the aircraft was reluctant to respond fully to aft cyclic input. It struck the surface in a nose-low, left-side first impact. The floats were inflated prior to entering the water but some of the four floats fitted to the skid landing gear were broken off on impact which resulted in the aircraft floating inverted just below the surface.

Simulator flight trials

During the simulator flight trials it was noted that if lowering the collective lever was delayed or if the lever was not lowered fully, the yaw continued at a rate dependent on lever position. The secondary

effect of the yaw was a significant loss of airspeed (40 kt) due to the change from forward to sideways flight. This change in direction caused the main rotor disk to flap back initiating a roll to the right which, even with a large opposing cyclic control movement, reached 45° before recovering to wings level. The helicopter nose pitched down 40° as the yaw continued in the right banked attitude. The pitch-down assisted in regaining the lost airspeed but the violent nature of the departure induced the immediate pilot reaction of moving the cyclic left and aft in order to prevent the helicopter departing further in pitch and roll. Having initially overcorrected the response to the departure in the simulator, it was then necessary to lower the nose positively in order to accelerate the aircraft to the 60 kt airspeed required in the Emergency Checklist.

The Emergency Checklist also instructs the pilot experiencing a drive shaft failure in flight, with regard to the collective lever and cyclic stick, to '*Adjust to obtain minimum sideslip angle and, if possible, level flight'*. It was found in the simulator that any attempt to raise the collective at 40 kt and above caused the helicopter to yaw to the right and the lever had to be lowered immediately to prevent the loss of airspeed and yaw roll couple occurring again. Below 40 KIAS the helicopter continued to yaw right and orbit to the right even with the collective lever fully down.

Aircraft flight trials

The flight trials in a BO 105 helicopter demonstrated that a height loss of 300 feet occurred during acceleration from 20 KIAS to 60 KIAS at wings level using 20° of nose-down pitch (as described by the witnesses). The time taken to achieve 60 KIAS was 7 seconds.

Organisational and management information

Operator's procedures

The helicopter was operated either from the ship, which the client used to provide support for their various facilities around the coast, or it was deployed to remote sites operating from shore based locations. Within the aircraft operator's operating procedures covering external load operations, comprehensive guidance and requirements were set out for conducting such operations. The three ground staff required were identified as the Load Dispatcher, Hook on Person and Load Receiver.

Personnel roles and responsibilities

Load Dispatcher (LD)

The person at the pick-up point who checks the preparation of the loads and the attachment slings. He ensures the safety at the pick-up point. He manages the despatch of the load by the groundcrew when carrying out the attachment of the load and the departure of the helicopter with the load by communicating instructions to the pilot using marshalling signals and/or radio communication.

Hook on Person (HoP)

Assists with the preparation of the loads and ensuring they are properly attached to the helicopter. When the helicopter moves vertically upwards to tension the attachment sling he ensures the sling is vertical and that the slings are not kinked or snagged and that the load is hanging correctly.

Load Receiver (LR)

Manages the delivery of the load at the drop-off point. Ensures the safety of the drop-off point environment and communicates instructions to the pilot through marshalling signals and/or radio communications.

Helicopter Landing Officer (HLO)

The person who is in control of the lifting operation and usually conducts the marshalling of the helicopter.

Client's procedures

The client provided staff trained as HLO to supervise load lifting operations either onboard the ship or at the remote operating sites. An HLO received a two-day training course organised by the operator which covered load preparation and marshalling. Loads were either assembled and inspected by the HLO onboard the ship or assembled onshore by the contractor and the lifting strops attached and the load inspected by the HLO. Within the client/operator contract it was clearly stated that the pilot was ultimately responsible for deciding if a load was suitable to be carried.

As part of a process of continuous development of advice between the client and the operator, an eleven point Health and Safety Notice was issued by the client on 13 September 2001 following some incidents during external load operations. Of particular relevance to the accident were:

Item 1. Helicopter operations will be carried out using trained and competent staff only. Refer to the appended schedule of trained staff.

Item 2. Each operation shall be staffed by an HLO at each side of the operation and a trained hooker on at the despatch side of the operation.

Item 5. All 3 members of staff will have radio communication between themselves and the pilot.

Operator's communications policy

The operator also stated its policy on communications in the Operations Manual. The relevant paragraph in relation to the accident was:

Communications

It is essential that there is adequate ability to communicate between the aircraft and the ground crew. This can be by standard marshalling signals but safety and efficiency can be significantly improved by providing the ground crew with A/G (air to ground) VHF radio sets linked to a helmet mounted headset. It is normally sufficient to provide the load dispatcher and load receiver with radio equipment, but it may be desirable to provide other members of the ground crew with an R/T reception only facility for passing urgent safety messages.

Whilst radios had been issued by the base manager at Stromness, the engineer at the lighthouse, who was acting as the HLO at the pick-up point, was not equipped with a radio. The HLO at the drop off point on the main island of Orkney had a radio and heard RTF, probably between the pilot and a manager at Stromness.

External load lifting techniques

The techniques adopted by the operator for the movement of external loads are set out below.

Flight Techniques

All external loads must be treated with extreme caution until their flying characteristics have been established.

Compact, dense loads with short strops tend to be the most stable. Light loads or loads with a large surface area can become very unstable with very little warning. It is sometimes necessary to add weight or alter the aerodynamic qualities of the load to make it more stable.

The safe cruise speed with any load is at least 5 kt below the onset of any noticeable vibration. It is quite common for loads to start a pendulous swing, particularly if the long strop is being used. This sort of swing is usually fairly benign but should be monitored closely.

Takeoff

The aircraft must be positioned so that the strop is absolutely vertical before taking the weight of the load to avoid dragging the load or creating unnecessary swing in the hover. Once established in the

hover, particular attention should be paid to the amount of power available to allow safe transition into forward flight. The aircraft should stay in the hover until it has been confirmed that the load is hanging correctly. This would normally be done by verbal signal from the aircrewman or a visual thumbs up from the ground dispatcher.

Transition into forward flight should be by slow acceleration and small control inputs. The load should be monitored closely during the acceleration for stability and security. The pilot should be prepared to reduce speed in the event of undesirable oscillations building up or, if the load becomes uncontrollable, to jettison. Depending on the surrounding area, it may be desirable to abort the take off onto a suitable area in front of the aircraft rather than attempting to fly a circuit back to the pick up point. Suitable emergency landing areas should be identified in the pre-flight survey of the operating area. When using a load strop, the pilot should note the radio altimeter height as the load lifts from the ground. This information will be useful during the subsequent approach to land the load. Caution should be exercised as it is possible for the rad alt to lock onto the load.

En Route

The maximum safe cruise speed with a load is unpredictable. If speed is increased gently, then any undesirable oscillations can be identified early and appropriate action taken before the load becomes uncontrollable. Oscillations can usually be damped by gentle reduction in airspeed and a gentle turn may help reduce lateral oscillations. On no account should the pilot attempt to correct the situation by cyclic input. This will invariably aggravate the situation. If the helicopter is fitted with SAS/AFCS or AP[1] and the cyclic is neutrally trimmed, oscillations can be reduced by lifting a hand off the cyclic and gently reducing collective. If speed has to be reduced below Vy[2], collective will have to be increased to inhibit unintentional descent. Pilots may find themselves close to a free air hover when trying to stabilise a load. In this event care must be taken to avoid vortex ring conditions. Once the load has been restabilised, the flight may be continued at reduced airspeed.

Load oscillation can also be induced by air turbulence. It is usually the pilot's control input, which will aggravate the oscillation. The experienced pilot will recognise this and will avoid unnecessary control inputs.

Use of hook release arming switch

The arming switch should be used to make the hook electrical release available for immediate jettisoning of the load during critical phases of flight. The hook should also be armed as a precautionary measure if at any stage of flight the stability of the load is causing concern as to the safety of the helicopter. The hook should be disarmed during stable transit to avoid inadvertent jettisoning of the load.

Repetitive Task Underslinging

It is normal practice when involved with high intensity repetitive underslinging operations for both ground crew and aircrew to start the day's flying fairly cautiously and speed up the round trip time as staff become more proficient. There is a fine line between swiftness and recklessness. Extreme care must be taken to avoid corner-cutting and complacency. Fatigue can also play a part. The warning signs can include omitting to carry out routine cockpit checks, losing track of the number of lifts already undertaken, excessive approach speeds etc. Although the flight time limitations in Section 7 of this manual put a limit on the length of underslinging sorties, pilots must be prepared to take a short break from the task if necessary. One must also consider the rest requirements of the ground teams who may be subject to physical fatigue.

Loss of the Tail Rotor

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[1] SAS/AFCS or AP = Stabilisation Augmentation System/Automatic Flight Control System or Autopilot.

[2] Vy = Best rate of climb speed on all engines.

The tail rotor on the BO 105 provides an anti-torque reaction to prevent the helicopter fuselage rotating to the right as a result of the torque generated by the turning of the main rotor blades in an anti-clockwise direction when viewed from above.

The aircraft Emergency-Checklist does not cover specifically the loss of tail rotor blades but it does describe to a limited extent the effects of a tail rotor drive shaft failure. Three conditions for tail rotor drive failure are given: 'Hover Inside Ground Effect (IGE)', 'Hover Outside Ground Effect (OGE)' and 'Flight'. For the Hover conditions, the indications would be 'Rapid uncontrolled right yawing motion' and the procedures are:

HOVER IGE

1. Collective Lever Full down

and simultaneously

2. Landing attitude Establish

After landing:

3. Double engine emergency shutdown Perform

HOVER OGE

1. Collective Lever Full down

If height permits:

2. Airspeed Gain

3. Double engine emergency shutdown Perform

4. Collective Lever Raise to stop descent and cushion landing

For the Flight condition, which was appropriate to this accident, the checklist states:

Tail Rotor Drive Failure - Flight

Conditions/Indications

Complete loss of tail rotor thrust

- Right yawing motion

Procedure

1. Collective lever and cyclic stick - Adjust to obtain minimum sideslip angle and, if possible, level flight

2. Airspeed - Maintain 60 KIAS or higher

3. Suitable autorotation landing area - Select

4. Autorotation - Perform

Editorial note: items in bold type within the procedures signifies memory items.

Analysis

Task preparation

On the day of the accident the required briefing of personnel had taken place and the various members of staff deployed to the lighthouse and shore sites. All the staff required to support the lifting operations were present; all were properly briefed and had conducted such operations on numerous occasions.

The pilot was properly qualified, rested and experienced to conduct the external load-lifting task. He was in good recent flying practice and there were no medical reasons for the accident. Moreover, he was under no pressure from needing to refuel or make up time.

Load behaviour

Having picked up the external load, a gentle climbing transition into forward flight was initiated to a height of approximately 400 feet probably climbing at about 40 KIAS. The airspeed may have been higher if the pilot was trying to increase his speed over the ground against the strong headwind. The helicopter was seen to level in height and the load trailed rearwards either due to the acceleration of the helicopter or the gusting wind. It was apparent that the acceleration of the load was strongly linked to the degree of swing and circular motion which resulted. The more rapid the acceleration, the greater the circular swinging motion but the load as constructed was highly unstable, particularly in the gusting wind conditions.

From the external load trial it was noted that the replica load became very unstable at about 60 kt. During the accident flight, through encountering turbulence from the cliff edge or surrounding terrain, the onset of instability may have occurred at a lower airspeed if the load acceleration was rapid.

Load construction

The loads at the lighthouse had been assembled by the contractor's staff in the presence of the client's representative but they could not recall the exact guidance they were given. There had been no means of weighing the prepared loads or the various components. Both the HLOs mentioned in this report were qualified to perform the duties of LD, HoP and LR. The pilot had not inspected the loads but after returning from Stromness, the engineer acting at the time as HLO and LD, together with the clients representative acting at the time as HoP, agreed that the shed sections and 'Portaloo' would not be flown due to their unstable load characteristics in the prevailing strong wind conditions. This decision demonstrates that they were evaluating the suitability of loads for carriage but they did not appreciate the potential instability of the load of scaffolding poles and conduit.

Knowledge of good practice for load construction was evident to JATEU staff and the client's HLOs had sufficient training and experience to know that the large slab sided sections of shed and the Portaloo were unsuitable for external carriage in the windy conditions. However, all the loads had been assembled by the building contractor's staff. They were sufficiently remote from the actual transfer task as not to be specifically trained in relation to helicopter lifting operations and consequently, little guidance was provided to them. The HLOs and the pilot had been extensively trained and had acquired practical experience of external load transfer but from his position hovering overhead the load, the pilot, who had the ultimate right to refuse to carry it, was poorly placed to observe and reject the load.

The fact that the light load of scaffolding frames and electrical conduit sections was likely to be highly unstable was not appreciated by anyone. Had the load been assembled and ballasted in accordance with military practice, this accident is unlikely to have occurred. The unsuitable preparation of the load could have been avoided if officially approved guidance on the correct methods for constructing aerial loads, targeted specifically at those persons who typically construct such loads, had been supplied to the client's staff (particularly the Load Dispatchers) and to the building contractor's staff. Suitably comprehensive written guidance was not widely available within the helicopter industry. Therefore, it is recommended that:

In consultation with the helicopter industry, the Civil Aviation Authority should produce guidance for the preparation, construction and carriage of external loads. This guidance should include methods of

improving the stability of loads that have poor or unpredictable flight characteristics. (Safety Recommendation 2003-37.)

Helicopter's manoeuvres after the tailstrike

When the load contacted the tail rotor, large sections of the tail rotor blades detached. The remains of the hub and blade grips stopped turning resulting in an instantaneous loss of tail rotor thrust. Next the helicopter was seen to yaw rapidly to the right, bank some 20° to the right and pitch nose-down. This was consistent with the reaction of the engineering simulator which, when the failure was simulated in level flight at 500 feet and 60 KIAS, yawed 60° to the right in less than two seconds, even when the collective lever was lowered within one second of the failure. Moreover, the flight trials demonstrated that it was probably not possible to attain the 60 KIAS airspeed specified in the Emergency Checklist within the height available. The height loss in this instance was probably due to a large increase in drag at the high sideslip angle. At an airspeed lower than 40 KIAS, the helicopter would have continued to turn to the right.

Following the initial 90° yaw to the right, the helicopter was seen to continue the turn to the right. At this point it was at best crosswind but probably slightly downwind. Initial attempts in the simulator to bring the aircraft under control led to a rolling and pitching motion, which was comparable to that described by the accident witnesses.

The turn to the right was probably a combination of: the pilot trying to continue the right turn into wind which, following the loss of the tail rotor was the easier direction; low airspeed, possibly below 40 KIAS; and possibly needing to raise the collective lever. This could have been necessary both to contain main rotor RPM which could have risen, and in trying to conserve height in order to turn into the strong wind.

The pilot would have commenced the flare for landing at between 75 and 100 feet above the water or lower if he had not achieved 60 kt. The surface of the sea was choppy with white caps on the waves providing a reasonable visual cue to assist depth perception. Despite the visual cues, judging height above the water is still difficult. Although the helicopter was fitted with a serviceable radio altimeter with an automatic voice warning at 100 feet, the point at which to raise the collective to cushion the touch down would still have had to have been assessed visually.

Helicopter condition

There was no evidence to indicate that at the time the tail rotor was struck, the aircraft was in other than a fully serviceable condition. The external load had been released before water impact occurred and the engine speed selector levers had been moved aft as far as, or beyond the IDLE position before water impact occurred. However, it was not possible to establish whether the speed selector levers had been moved as far as the CUT OFF position. Nevertheless, the assumed displacement of the speed select levers away from the governed position prior to impact was consistent with the reduced main RRPM deduced from the blade examination. It is probable that in the short time available, estimated as between 10 to 15 seconds depending on the amount of collective applied and speed attained in the descent, the pilot was unable to shut down both engines. The witnesses who saw the helicopter impact the sea stated that it orbited to the right a number of times and appeared to drop from about 30 feet, entering the water heavily in a nose-up attitude banked steeply to the right. This was consistent with the damage to the aircraft, which showed a high vertical and rearwards impact.

If the engine SSLs were only retarded to IDLE, or if one was at IDLE and the other forward but out of the governed range, as the collective lever was raised and the rotor RPM decayed, the freewheel units would have re-engaged the engines to the power train. This would have caused the yaw to the right. However, the RRPM would still have continued to decay because, with the engines at a low power setting, there would have been insufficient power to sustain the RRPM. The helicopter would then have dropped rapidly with the large lateral and vertical g forces experienced at that point by the pilot, adding considerably to his difficulties in maintaining the helicopter in a level attitude.

Helicopter control after a loss of tail rotor effectiveness

Although the provision of suitable guidance material and training should reduce the likelihood of tail rotor damage due to external load strikes, it is unlikely to eliminate them entirely. Consequently, measures aimed at improving a pilot's chances of successfully coping with a loss of tail rotor effectiveness could reduce the severity of the repercussions.

The reports of previous accidents clearly indicated how rapidly the helicopters yawed to the right initially, and with any subsequent application of the collective lever once established in the descent if the engines were at IDLE. This yawing effect was combined with the induced rolling and pitching motion and significant loss of IAS.

In two reports, both engines were shut down and both helicopters made successful water landings, remaining upright on their inflated emergency floats. In cases where the engines were not shut down or at IDLE, when the helicopter was flared to reduce speed for touch down, the rapid yaw to the right was accompanied by large pitching moments requiring similarly large control inputs to try and maintain the helicopter in a level attitude. With both engines shut down, when the collective lever is raised the nose of the helicopter will yaw to the left slightly due to main gearbox friction but this yawing effect is likely to be benign and will reduce rapidly with the decay in main rotor RPM.

Following a loss of tail rotor thrust, if the engines are not shut down but left at IDLE or in the governed range, when the collective pitch lever is raised, the rate of yaw will be very rapid. This was measured in the simulator to be as high as 360° in 2.5 seconds, making attitude holding in pitch very difficult. Pitch excursions of +/- 40° were recorded on one occasion partly due to lack of visual cues in the fixed base simulator although to a degree this was balanced by the lack of vertical g forces and rotation which, in the accident aircraft, could have been disorientating.

Information to pilots

If helicopter pilots are to have a reasonable chance of successfully coping with a loss of tail rotor effectiveness, the flight characteristics of a helicopter following the loss should be predicted as accurately as possible during the certification process. This information should be promulgated in the Rotorcraft Flight Manual for the type with any emergency or abnormal procedures and limitations. Any advisory areas in terms of height and velocity where recovery from the loss of a tail rotor may not be possible should also be published in a diagram. Therefore it is recommended that:

The Civil Aviation Authority should take forward a proposal to the appropriate helicopter manufacturers and type certification bodies that the flight characteristics of a helicopter following the loss of tail rotor effectiveness should be promulgated in every helicopter type's Flight Manual. (Safety Recommendation 2003-38.)

It was also noted that the severity of the yaw to the right with the associated rolling, pitching nose down and loss of airspeed were not indicated in either the Rotorcraft Flight Manual or the Emergency Checklist. This information may also be relevant to other types for which such information may also not be published. Therefore, it is recommended that:

The Civil Aviation Authority should consider providing a tail rotor failure safety information package to all helicopter pilots and operators to improve their awareness of the effects of the loss of tail rotor thrust. (Safety recommendation 2003-39.)

Checklist improvements

It was noted in the Emergency Checklist that only within the IGE and OGE cases does the checklist state to perform a 'double engine emergency shutdown'. The Flight case requires an autorotation to be performed, which does not specifically mean shutting down the engines. What was probably intended was an instruction to carry out the **Autorotation Procedure** which was listed elsewhere in the Manual under the heading of 'Engine Emergency Conditions' but this intention was not made clear to the reader. That procedure includes the instruction **'Double engine emergency shutdown - perform'** as a memory item before the aircraft is flared for landing.

The vital importance of shutting down the engines has been illustrated by this accident, previous accidents and the simulator trials. Moreover, it is not practicable for the pilot to refer to the checklist following a tail rotor failure but the checklist was not comprised exclusively of recall items. Therefore, it is recommended that:

Eurocopter should review the '*Tail Rotor Drive Failure - Flight'*, emergency procedure included in the BO 105 rotorcraft flight manual. Specifically Eurocopter should consider the following aspects:

a. Whether the procedure regarding use of the collective lever and cyclic stick, in order to, *'if possible maintain level flight'*, is realistic since it may in fact de-stabilise the aircraft.

b. Emphasise the importance of carrying out a double engine emergency shut-down after a tail rotor failure in forward flight before attempting an autorotative forced landing.

c. Ensuring that all the actions required within the emergency drill are memory items.

(Safety Recommendation 2003-40.)

Radio Communications

It was clear that both client and operator had set in place the correct structure for conducting external load operations and had provided the required equipment such as the air-to-ground radio sets. Whilst being equipped with a radio was a requirement of the client, the use of marshalling signals was the basic requirement of the operator. That requirement was met; the air-to-ground radio was an additional safety and efficiency benefit.

From the evidence of witnesses, the movement of the load initially was no different to that of other loads of a similar external load configuration. The movement would probably not have warranted a warning to the pilot who should have been able to monitor the oscillations of the load in the mirror providing it was properly adjusted. The movement of the load, which caused the contact with the tail rotor, was very rapid and it could not be determined if there was sufficient time for a warning to be transmitted. It was considered, however, that equipping personnel carrying out external load operations with two way radio communications was a significant safety benefit. Therefore, it is recommended that:

The Civil Aviation Authority should consider recommending two way radio communication between a pilot undertaking external load lifting operations and persons at the pick-up and drop points when another crew member is not available onboard the helicopter to monitor the behaviour of the external load. (Safety Recommendation 2003-41.)

Survival measures

During the impact with the sea surface the pilot received a serious injury to the back of his head. He was not wearing a protective helmet and there was no regulatory or operator requirements to do so. However, the wearing of protective helmets is required by the Civil Aviation Authority for pilots undertaking powerline inspections. This is a condition to be met when transit flying at low height permitted by an exemption to the Rule 5 of the Rules of the Air. The requirement to wear helmets presumably arises from the perceived level of risk. The risks inherent in external load transfer are probably as great if not greater than those associated with powerline inspection. Therefore, it was recommended that:

The Civil Aviation Authority should consider recommending the wearing of protective flying helmets for flight crews carrying out external load lifting operations. (Safety Recommendation 2003-42.)

Conclusions

The direct cause of the accident was an external load striking the tail rotor blades when the helicopter was transiting at approximately 400 feet and 60 kt. The pilot probably released the load immediately after it struck the tail rotor. The load was low density, slab-sided and prone to instability due to its weight and construction, especially in the gusting 35 kt wind. The loss of a substantial part of the tail

rotor blades caused the helicopter to yaw to the right and then describe a descending orbit to the right, which was probably assisted by the pilot trying to turn the helicopter into wind. It is unlikely that in the short time available the pilot was able to shut down both engines. During his efforts to carry out an emergency landing on the water, the aircraft rotated uncontrollably and entered the water backwards with a very high rate of descent, fatally injuring the pilot.

The primary reason for this accident was the attempted transfer of an external load which proved to be unstable in flight. The load had been assembled by untrained building contractor's staff who were remote from the actual lifting operation. Moreover, the pilot, who had the ultimate right to refuse to carry it, was poorly placed to observe and reject the load. Suitable written guidance on load construction was not widely available to persons tasked with assembling and assessing external loads. Recurrences of this scenario could be reduced by the provision of suitable and authoritative guidance to those persons who typically assemble the loads.

The simulator trials and the insights drawn from previous accidents involving tail rotor failure demonstrated that it is essential to shut down both engines before carrying out a forced landing. This is necessary to prevent the helicopter rotating to the right and inducing pitch excursions as the collective lever is raised to cushion the touch down. Information within the Flight Manual and the Emergency Checklist did not adequately address these factors. Finally, the pilot received a serious injury to the back of his head when the helicopter struck the sea with a high vertical velocity and travelling backwards. He was not wearing a protective helmet and there was no requirement to do so.

Safety Recommendations

Arising from this investigation, the following safety recommendations were made:

Safety Recommendation 2003-37

In consultation with the helicopter industry, the Civil Aviation Authority should produce guidance for the preparation, construction and carriage of external loads. This guidance should include methods of improving the stability of loads that have poor or unpredictable flight characteristics.

Safety Recommendation 2003-38

The Civil Aviation Authority should take forward a proposal to the appropriate helicopter manufacturers and type certification bodies that the flight characteristics of a helicopter following the loss of tail rotor effectiveness should be promulgated in every helicopter type's Flight Manual.

Safety Recommendation 2003-39

The Civil Aviation Authority should consider providing a tail rotor failure safety information package to all helicopter pilots and operators to improve their awareness of the effects of the loss of tail rotor thrust. (Safety recommendation 2003-39.)

Safety Recommendation 2003-40

Eurocopter should review the 'Tail Rotor Drive Failure - Flight', emergency procedure included in the BO 105 rotorcraft flight manual. Specifically Eurocopter should consider the following aspects:

a. Whether the procedure regarding use of the collective lever and cyclic stick, in order to, *'if possible maintain level flight'*, is realistic since it may in fact de-stabilise the aircraft.

b. Emphasise the importance of carrying out a double engine emergency shut-down after a tail rotor failure in forward flight before attempting an autorotative forced landing.

c. Ensuring that all the actions required within the emergency drill are memory items.

Safety Recommendation 2003-41

The Civil Aviation Authority should consider recommending two way radio communication between a pilot undertaking external load lifting operations and persons at the pick-up and drop points when another crew member is not available onboard the helicopter to monitor the behaviour of the external load.

Safety Recommendation 2003-42

The Civil Aviation Authority should consider recommending the wearing of protective flying helmets for flight crews carrying out external load lifting operations.