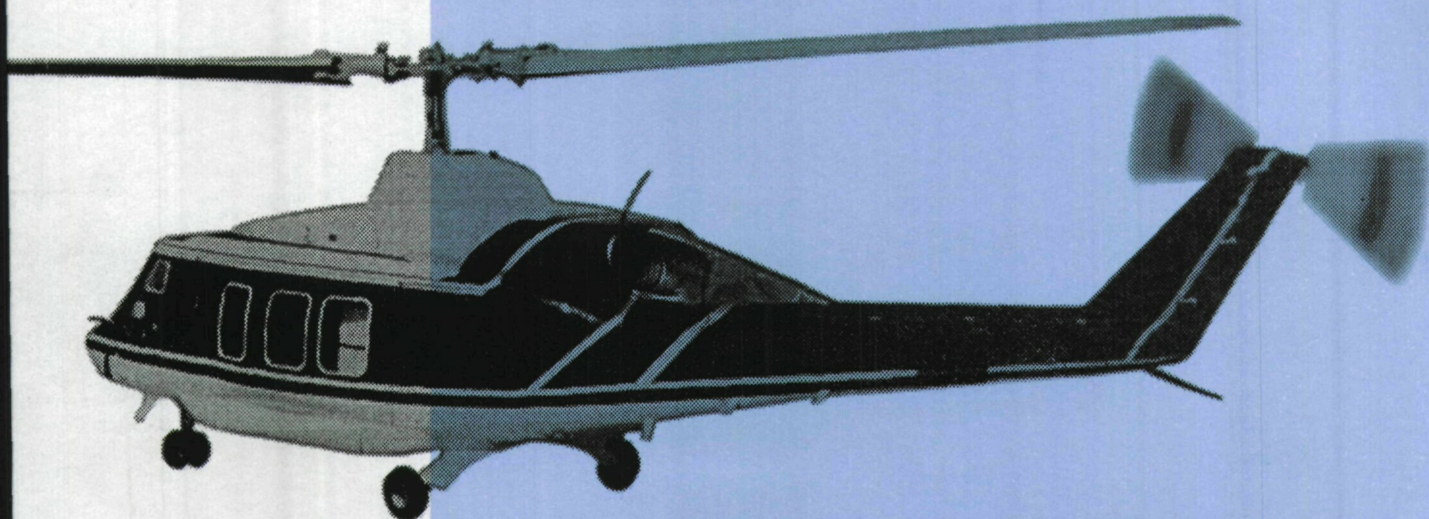
BUREAU OF AIR SAFETY INVESTIGATION REPORT

BASI Report B/885/1005



Bell 214ST Helicopter VH-LAO 100 km north-west of Troughton Island WA 28 March 1988

BASi

Bureau of Air Safety Investigation

COMMONWEALTH DEPARTMENT OF
TRANSPORT AND REGIONAL DEVELOPMENT

Department of Transport

Bureau of Air Safety Investigation

ACCIDENT INVESTIGATION REPORT
B/885/1005

Bell 214ST Helicopter VH-LAO
100 km north-west of Troughton Island WA

Latitude 13° 15' 19.3" south
Longitude 125° 23' 11.9" east

28 March 1988

BASi
Bureau of Air Safety Investigation

Released by the Director of the Bureau of Air Safety Investigation under the provisions of Air Navigation Regulation 283

When the Bureau makes recommendations as a result of its investigations or research, safety, (in accordance with our charter), is its primary consideration. However, the Bureau fully recognises that the implementation of recommendations arising from its investigations will in some cases incur a cost to the industry.

Readers should note that the information in BASI reports is provided to promote aviation safety: in no case is it intended to imply blame or liability.

ISBN 0 642 19249 9 March 1993

This report was produced by the Bureau of Air Safety Investigation (BASI), PO Box 967, Civic Square ACT 2608.

The Director of the Bureau authorised the investigation and the publication of this report pursuant to his delegated powers conferred by Air Navigation Regulations 278 and 283 respectively. Readers are advised that the Bureau investigates for the sole purpose of enhancing aviation safety. Consequently, Bureau reports are confined to matters of safety significance and may be misleading if used for any other purpose.

CONTENTS

Local time is Coordinated Universal Time + 8 h

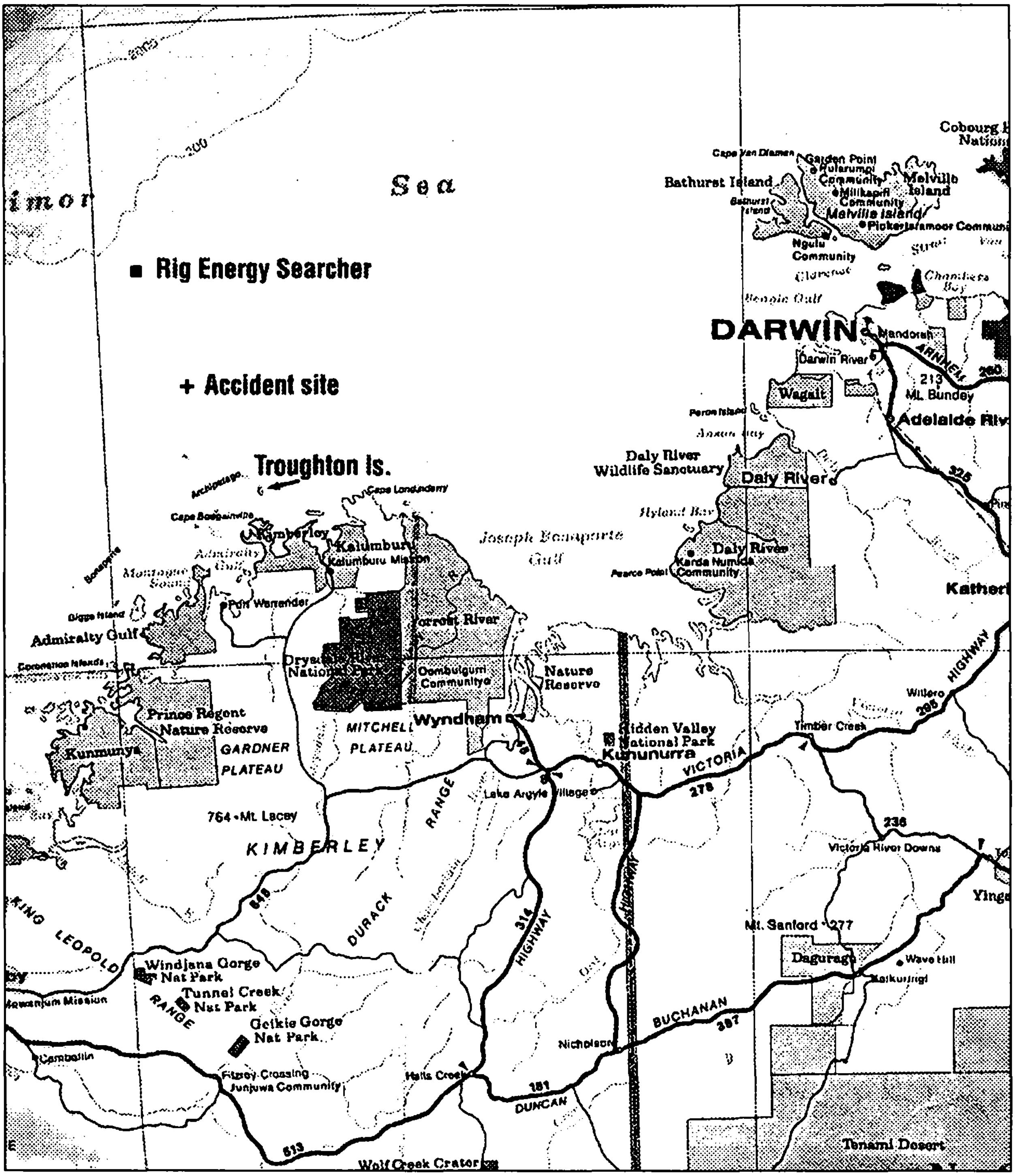


Figure 1. Map of the accident site

SYNOPSIS

The accident occurred in international waters. Since the aircraft was registered in Australia and was operating on behalf of an Australian company, the Bureau of Air Safety Investigation (BASI) assumed responsibility for the investigation of the accident.

The helicopter was cruising at 4,500 ft en route from Troughton Island to the drilling vessel *Energy Searcher* when a loud bang was heard. At the same time, violent airframe vibrations forced the crew to reduce engine power and enter a descent. In the subsequent ditching, the helicopter overturned but all occupants were able to egress safely and were later rescued. The helicopter eventually sank in 60 m of water, but the wreckage was recovered for examination.

The report concludes that the vibration was caused by mass unbalance of the main rotor following the fatigue failure of one main rotor drag brace barrel. The fatigue occurred because the drag brace in-flight loads overcame the pre-load applied by the drag brace nut torque. Research indicates that the nut torque may have been below the specified value.

1. FACTUAL INFORMATION

1.1 History of the flight

The helicopter was on a 65-min flight from Troughton Island to the drilling vessel *Energy Searcher*. The flight departed Troughton Island at 0717 hours Western Standard Time with thirteen passengers and two crew on board.

Approximately 30 min after takeoff, while cruising at 4,500 ft, a loud bang was heard accompanied by the onset of severe airframe vibration. The pilot immediately lowered the collective pitch control and reduced the helicopter's speed, while the co-pilot transmitted a distress message and instructed the passengers to fasten their seat belts.

Although the vibration made reading of the instruments difficult, the pilot was able to determine that main rotor RPM was approaching 120%. The pilot increased the collective pitch in an attempt to control the main rotor RPM but this caused the vibration level to increase. He then lowered the collective pitch control, turned the helicopter into wind, and established an autorotative descent. The pilot observed that one main rotor blade was tracking irregularly. Passing 1,000 ft, the automatic inflation system for the flotation bags was armed.

The helicopter contacted the water surface at a forward speed of 10–15 kts approximately parallel to the swell. The flotation bags immediately began to inflate. At the same time the main rotor blades struck the water, causing the fuselage to roll right until inverted. During the rollover, the left and right cabin windows were forced from their frames and the left side hinged door forced open. All passengers escaped from the cabin through these openings. The pilots exited through their respective doors, the co-pilot taking a portable emergency locator beacon.

The short time interval between touchdown and the rollover prevented deployment of the life rafts. However, one raft was later released by a passenger.

The survivors were located a short time after the ditching by a search aircraft and were later rescued by another helicopter and transferred to Troughton Island.

1.2 Injuries to persons

Injuries	Crew	Passengers	Other
Fatal	–	–	–
Serious	–	–	–
Minor/None	2	13	–
Total	2	13	–

1.3 Damage to aircraft

In-flight damage was restricted to one main rotor drag brace. The helicopter sustained substantial damage during the ditching, primarily to the two main rotor blades. All four flotation bags were eventually torn away by the action of the sea.

1.4 Other damage

Nil

1.5 Personnel information

The pilot in command was aged 49 years. He held a current Senior Commercial Pilot Licence (Helicopters) with a valid medical certificate and was endorsed to fly Bell 214ST helicopters. At the time of the accident, the pilot had a total flying experience of 8,250 h, of which 400 h were on Bell 214ST helicopters.

The co-pilot was aged 26 years. He held a current Commercial Pilot Licence (Helicopters) with a valid medical certificate and was endorsed to fly Bell 214ST helicopters.

No further information relating to the pilots' experience was available.

The licensed aircraft maintenance engineer who was responsible for the adjustments to the main rotor head—including the drag braces—following the fitment of the rotor head on 13 September 1987, was correctly licensed, held the appropriate qualifications, and was experienced in Bell 214ST maintenance.

1.6 Aircraft information

The aircraft, registered in Australia as VH-LAO, Serial Number 28116, was manufactured by Bell Helicopter Textron in the USA in 1983. It had completed 2,438 h at the time of the accident. Valid Certificates of Airworthiness and Registration and a current Maintenance Release were in force.

The weight and centre of gravity were within specified limits, and there was adequate fuel on board to complete the flight.

1.7 Meteorological information

The weather at the time of the accident was one eighth of stratocumulus cloud at 1,500 ft and a surface wind 160° magnetic at 10 kts. Visibility was greater than 10 km and the sea state was rough with a 2–3 m swell. The water temperature was 31°C.

1.8 Aids to navigation

Not relevant.

1.9 Communications equipment

The crew made a mayday call which was received by both Darwin and Kununurra. The portable emergency locator beacon carried by the co-pilot provided a signal that was used by the search aircraft.

1.10 Aerodrome information

Not relevant.

1.11 Flight recorder

The helicopter was not fitted nor required to be fitted with a flight data recorder.

The helicopter was fitted with a Fairchild A100A four-track cockpit voice recorder. The recording medium was an endless-loop, plastic based, magnetic tape with a recording duration of 30 min. Although salt water had penetrated the unit and caused corrosion on the tape transport assembly, the magnetic tape was intact.

The pilots' conversation was recorded clearly on channels 1 and 2 and cockpit noise was recorded by an area microphone on channel 3.

An analysis of the recording indicated that the helicopter was functioning normally until the onset of the vibration. The recording showed broadband signals, known as main rotor 'beat', caused by rotation of the main rotor blades. The period between the 'beats' varied after the vibration began.

1.12 Impact information and wreckage examination

1.12.1 Impact information

The helicopter contacted the water at a low rate of descent and at low forward speed. The flotation bags began to inflate on entering the water. Both main rotor blades struck the water, causing the fuselage to overturn. During the rollover, the left and right cabin windows were forced from their frames and the left side hinged door pushed open. Apart from a section of the right fuselage flotation bag, which was punctured during the preceding sequence, the remaining bags (part of the right fuselage bag, the left fuselage bag, and left and right tail boom bags) kept the inverted helicopter afloat for approximately 40 min before the sea state caused them to break away. The helicopter then sank in 60 m of water. The flotation bags were not recovered and the reason for the puncture in the right fuselage bag was not established.

1.12.2 Wreckage examination

Using the signals from the underwater locator beacon, the substantially intact wreckage was located eight days after the accident on the seabed 5 km east-south-east of the point where the survivors were found. The helicopter was examined by a camera-equipped remotely operated vehicle. The principal observation was that one main rotor drag brace had broken just inside the inboard nut.

The wreckage was recovered and examined in detail. It was established that all damage apart from the broken drag brace from one main rotor blade was a result of the collision with the water and/or salt water immersion. The broken drag brace was subjected to extensive inspection and testing.

1.12.3 Description of the drag brace assembly

The components and layout of the rotor head and drag brace assembly are displayed in figures 2 and 3.

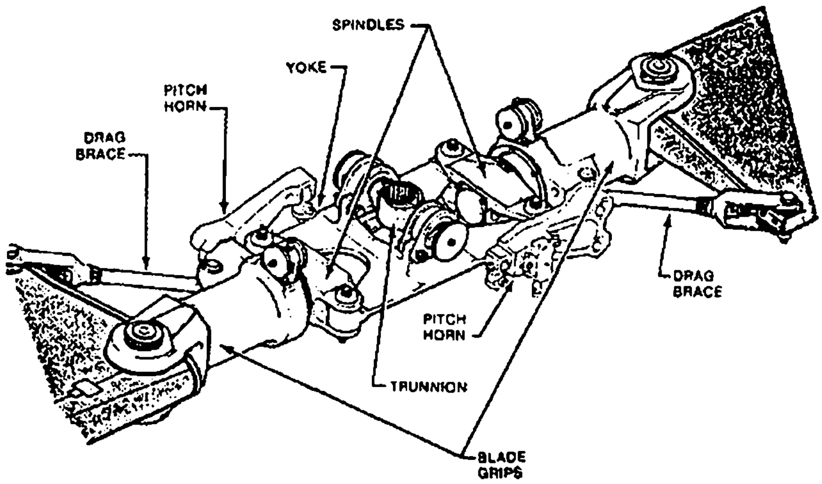


Figure 2. Layout of rotor head

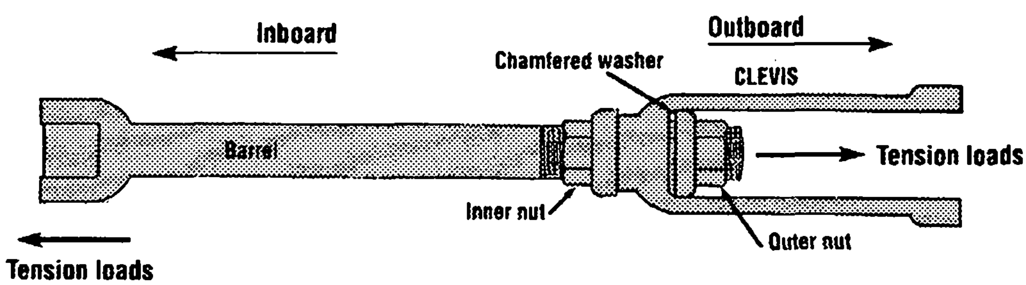


Figure 3. Layout of drag brace assembly

In order to adjust the sweep of each blade, the inner and outer nuts on each barrel are moved until the sweep is correct. The outer nut is held in position with a ring spanner while the inner nut is tightened with a torque wrench until the torque is between 375 and 425 ft lb. Several attempts are usually necessary to achieve the correct blade sweep coincident with final nut torque. Final installation is completed by the addition of a locking wire between the two nuts and the addition of corrosion preventative compound to the joint.

1.12.4 Component history of the drag brace assembly and main rotor head

At the time of the accident the aircraft had flown 2,438 h. The main rotor blades were the original fit; however, the complete main rotor hub assembly was replaced on 13 September 1987 at 2,040 flying hours. The main rotor hub assembly was a PN 214-010-100-183 type and its serial number was A-196. The hub was of the latest type produced for the 214ST helicopter and incorporated coning/droop stops.

The drag braces were replaced with the head and had therefore flown 398 h at the time of the accident. They both displayed the latest part number (PN 214-010-113-105) and incorporated the following components:

Component	Part Number	Retirement Life
Barrel	PN 214-010-120-107	2,500 h
Clevis	PN 214-010-121-105	No restriction
Nut	PN 214-010-198-101	2,500 h
Washer	PN 214-007-97-66A5	No restriction

Table 1. Drag brace component details

The drag brace assembly was introduced into service by Bell Helicopter Textron Alert Service Bulletin 214ST-86-35 of 31 March 1986 and replaced the original drag brace assembly PN 214-010-113-001. The original drag brace assembly was susceptible to corrosion damage in service including the possible early failure of the drag brace due to fatigue cracking commencing at corrosion pits. The replacement drag brace was similar in design to the original except for ground threads on the barrel instead of machined threads and improved corrosion protection. In addition the nuts were locked with locking wire instead of being crimped and therefore self locking.

1.12.5 Examination of broken drag brace

The location of the failure within the inboard clevis retaining nut is shown in figure 4.

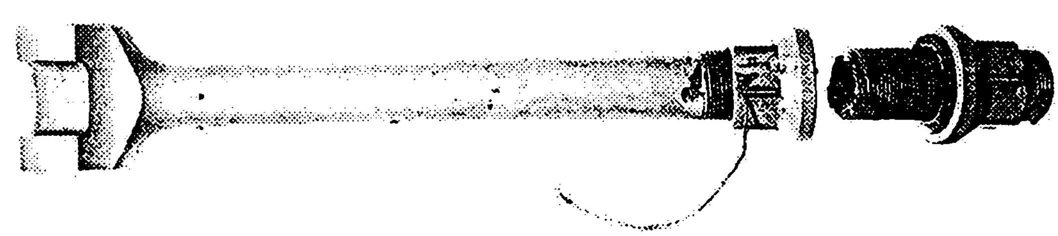


Figure 4. Drag brace barrel failure location

Marks on the corners of both the inboard and outboard nuts indicated that a spanner had been used to turn the nuts in both directions at some time prior to the failure. No defects or irregularities were found on the outboard nut apart from some fretting on the face which was in contact with the chamfered washer. Lockwire had been installed on the nuts.

1.12.5.1 Examination of the drag brace barrel

The fracture surface of the barrel is shown in figure 5. The fracture surface was relatively flat and contained a number of clearly visible progress lines typical of a fatigue-induced fracture.

Initial inspection of the fracture surfaces found that the fatigue fracture of the barrel commenced within the inner drag brace nut in the root of the third thread from the bearing face of the nut. The primary crack initiated on the outboard side (normally unloaded) of the root radius of the thread. It was located in the lower leading quadrant of the barrel at about the five o'clock position. There was no evidence of corrosion or material defect at the fracture location.

It was apparent that crack initiation had occurred under high stress yet the rate of crack growth was slow. The crack grew symmetrically across the barrel with final overload failure occurring when about 2% of the sectional area remained. This indicated that loads progressively reduced as the crack grew.

Cadmium plating had been removed from localised areas of sections of the thread which had been in contact with the inboard nut. Fretting damage was found in a number of areas on the thread flanks. It was apparent that the area of contact between the two threads was not continuous. Areas of the thread showed no evidence of damage resulting from nut tightening. Deformation and damage to the cadmium plating on the barrel thread caused by contact with the inboard nut was evident on both the outboard and inboard flanks. (Damage to the cadmium plating on the thread caused by nut tightening would be expected to affect only the outboard flanks.)

The cadmium plating on the threaded section of the barrel in contact with the outboard nut was extensively damaged. The fretting damage was such that the cadmium had been removed from the flanks of the barrel thread and piled up in the roots of the thread consistent with relative movement between the nut and the barrel. Deformation and damage to the cadmium plating on the barrel thread were evident on both the outboard and inboard flanks. (Damage to the cadmium plating caused by a tight nut would be expected to affect only the inboard flanks.)

The barrel threads, located inside the clevis, exhibited damage consistent with contact between the threads and the inside of the clevis.

1.12.5.2 Examination of the drag brace inboard clevis nut, chamfered washer and clevis

Substantial areas of the inboard nut thread showed no evidence of damage caused by nut tightening. On isolated sections of the thread, the cadmium plating had been worn away in an uneven manner. Fretting damage was observed on the face of the nut that was in contact with the clevis.

The nut had small fatigue cracks in the root of the first and fifth threads. The crack in the first thread had extended to the face of the nut, allowing a small piece of the nut to break away.

Some non-uniformities in the pitch and form of the thread of the nut were noted, particularly in the area corresponding to the main crack in the barrel. Some were outside the allowable tolerance for nut manufacture. One of the non-uniformities—a narrowing of the thread crest—corresponded to the location of the origin of the primary crack and similar faults were evident on each fourth thread. The nut could be installed on the barrel without interference and in this regard the thread was within tolerance.

The chamfered washer exhibited fretting damage on the side in contact with the clevis.

The bore of the clevis showed thread-like marks and both faces of the clevis exhibited fretting.

1.12.5.3 Examination of the fracture surface

Microscopic examination revealed 343 evenly spaced bands of fatigue striations on the fracture surface, each consisting of about 60–80 individual striations.

1.13 Medical and pathological information

Neither pilot had any medical or psychological condition which might have contributed to the accident.

1.14 Fire

Not relevant.

1.15 Survival aspects

Shortly after the onset of the emergency, the crew transmitted a distress message and briefed the passengers to prepare for ditching. Also, one of the passengers was instructed on the operation of the life raft deployment system.

All passengers had received training in emergency ditching drills, were given an emergency brief before the flight, and were wearing life jackets for the flight. Although most of the passengers had not received specific training in egress from a submerged and inverted helicopter, all were able to escape from the helicopter through the window openings and doors which had been breached by the water as the helicopter rolled inverted.

The passenger who was instructed to operate the life raft deployment system was prevented from doing so by the influx of water into the fuselage. He was later able to deploy one life raft by diving under the helicopter fuselage. However, he experienced difficulty in operating the manual release lever on the life raft compartment door and had to make three dives before the raft was released. One compartment of the raft was punctured during the inflation cycle and it was able to support, fully, only six survivors. The remainder stayed in the water alongside the raft, supported by life jackets. A number of survivors were affected by aviation turbine fuel in the water and those worst affected boarded the life raft.

Search aircraft used signals from the emergency locator beacon taken from the helicopter by the co-pilot to locate the survivors. The operating company maintained a dedicated search and rescue helicopter on standby at Troughton Island. This and two other helicopters arrived at the site about 1 h after the ditching, with all survivors of the accident being returned to Troughton Island after a further 2 h.

1.16 Tests and research

A considerable amount of inspection, research and testing was carried out on both drag braces by a number of separate organisations resulting in 39 specialist, technical and other reports. Only the main, relevant findings of these reports are covered in this section.

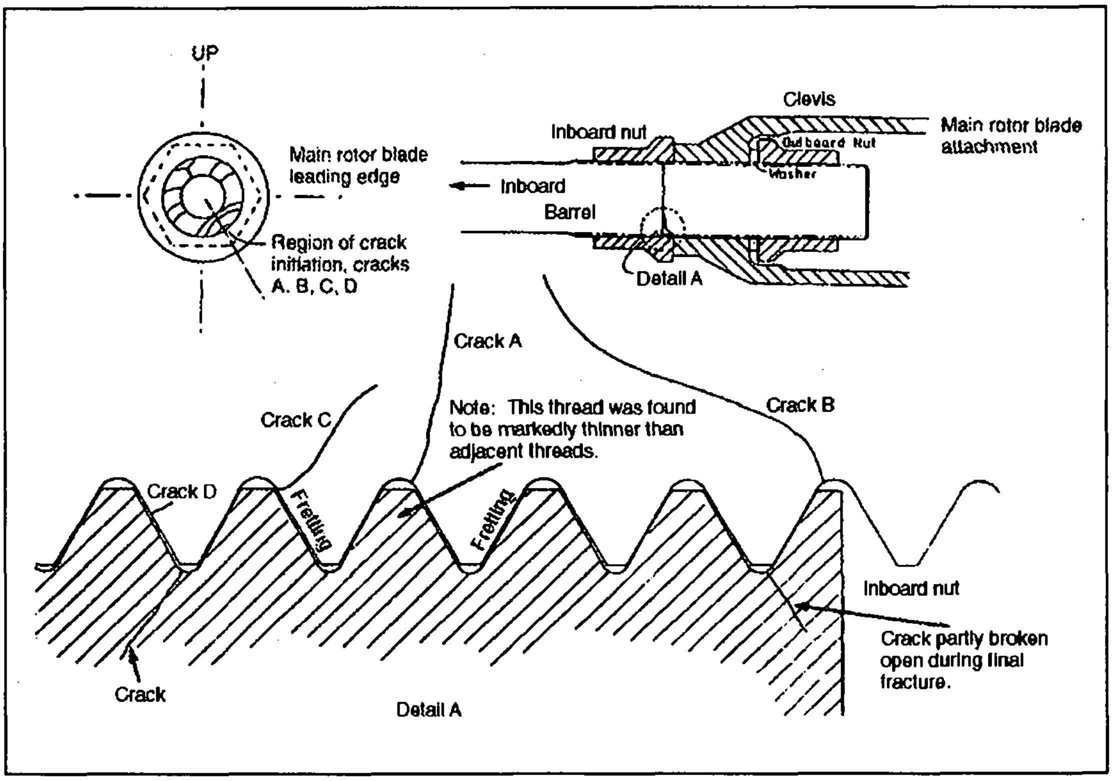


Figure 5. Detail of fracture and cracks

1.16.1 Drag brace loads (axial and bending)

An analysis of the loadings on the drag brace indicated that:

(a) excessive in-flight loading had not occurred;

(b) compressive loads were unlikely to have caused the cracking;

(c) cracking was consistent with the third thread being unloaded or loaded in the opposite direction to that which was expected; and

(d) bending loads were present.

It was also determined that in a normal drag brace configuration, the stress at the failure position due to bending loads is small but increases as pre-load is reduced.

1.16.2 Fatigue testing

Fatigue testing indicated in broad terms that low drag brace pre-load conditions would result in barrel failure at the location and within a time frame similar to that involved with the failure of the drag brace from VH-LAO.

1.16.3 Thread variations and loads

Analysis of the thread conditions indicated that thread contact between the inboard nut and corresponding barrel threads was not continuous. Variations in pitch and the thread form of the inboard nut were found. Whilst one pitch variation was outside the required tolerance the average of pitch variations was not. The variations were too small to be detected during the normal manufacturing quality control process.

Previous work on variations in thread profile and pitch indicated that these can have an effect on pre-load. The actual reduction in pre-load caused by the variations in the inboard nut of VH-LAO could not be determined; however, as the variations were minor in nature it was calculated that the reduction in pre-load would be unlikely to reach the magnitude required to cause fatigue cracking to start where it did.

Calculations on the order of thread take-up caused by the pitch variations indicated that maximum thread loading occurred on thread faces other than the one where cracking started.

It was apparent that narrowing of the thread crest in the vicinity of the fracture origin caused the thread outboard face to be unloaded. Calculations indicated that whilst the variation in thread form caused an increase in the stress in the vicinity of the fracture origin, the maximum stress in this area was still below that achieved in other threads and cracking was therefore more likely to occur in other threads first.

1.17 Other information

1.17.1 Drag brace installation

An inspection of the aircraft records indicated that the drag brace assembly had been fitted to the helicopter 398 flying hours before the accident. During the fitting process one or more of the drag brace nuts had been both un-torqued and torqued as part of blade tracking adjustment. The operator had in place at the time an approved maintenance scheme involving duplicate inspections of any work done to the main rotor system. No direct evidence was found which indicated that the maintenance personnel failed to complete the maintenance procedures set out in the operator's maintenance documents.

1.17.2 Previous drag brace failure

On 14 August 1985, a drag brace failure occurred to a Bell 214ST near Aberdeen, Scotland. The failure was caused by fatigue which was initiated by corrosion pitting of the thread surface. Subsequent modifications to the drag brace made the assembly more corrosion resistant, and a modified drag brace was fitted to VH-LAO at the time of this accident.

1.17.3 Other records

A search of US records did not reveal any cases where a torqued drag brace nut had lost tension during flight or other failures other than the one mentioned in 1.17.2.

2. ANALYSIS

2.1 In-flight failure

The vibration experienced by the aircraft and occupants, together with the pilot's observations and the uneven beat frequency observed during cockpit voice recorder readout, are indicative of drag brace failure. No other evidence of pre-impact failure was found.

The drag brace failure forced the crew to carry out a controlled ditching in rough seas which resulted in an emergency evacuation of the helicopter and its subsequent sinking.

2.2 Assessment of the reasons for drag brace failure

2.2.1 Overview

It was determined that the drag brace failed due to the initiation and growth of a fatigue crack. Material defects did not contribute to the initiation of the fatigue crack and the relatively slow crack growth and large crack size at final failure. Most of the nut thread deformation was due to the passing of drag brace loads through the nut as the fracture progressed.

From previous experience and data concerning fatigue crack growth in aircraft components, it was deduced that each band of striations on the fracture surface of the barrel represented one flight cycle (takeoff to landing). Thus, the fracture had been growing for at least 343 flights.

The average sortie time for VH-LAO was 1 h. Thus, it was likely that the crack had initiated shortly after the drag brace assembly had been fitted to the helicopter some 398 flying hours before the accident.

Under normal conditions, drag brace loading will result in the highest stresses being at the inboard side of the root radius of the barrel thread and thus, if cracking is to occur whilst the nut is loaded, it should commence at this position. The cracking on the failed drag brace initiated on the outboard and normally unloaded side of the thread.

Fatigue cracking can only occur if the area is subjected to excessive cyclic loads. The twin nut and clevis is designed to reduce the cyclic stress in the area between the nuts. If the nuts were torqued correctly and were applying the designed pre-load, cyclic stress loads in the vicinity of the third thread should have been well below that required to initiate fatigue cracking.

Tests and research indicated that there is a significant reduction in the fatigue life of the barrel as pre-load falls. In particular at very low pre-loads the predicted life is of similar magnitude to that achieved by the drag brace on VH-LAO.

2.2.2 Conditions required for cracking to commence

Areas of the cadmium plating on the threads of both the barrel and the nuts were badly worn—a condition consistent with relative movement between the threads on the nuts and the barrel. There were also areas where the wear between the nut and barrel thread was limited or non-existent—in particular, on those threads inboard of the primary crack. The presence of cadmium on the fracture face indicated that the cadmium coating was being worn away while the crack was growing. The wear pattern was consistent with the axial load exceeding the pre-load in the barrel, thus allowing the nut to work. In contrast, the threads on the barrel and nuts of the intact drag brace exhibited only limited damage to the cadmium plating, indicating that pre-load had not been exceeded.

Investigation indicated that the cracking would commence where it did only if one or more of the following conditions applied:

(a) The drag brace axial loads were sufficient to overcome the pre-load in the barrel due to nut torque (assuming the nut and barrel threads were normal and the nut had been torqued to specifications).

(b) There were upward bending loads on the drag brace in addition to the axial loads.

(c) There was a thread deformity which significantly reduced the pre-load in the barrel when the nuts were torqued to specifications.

(d) There was a thread deformity which caused a stress concentration in the area of the crack.

(e) The nuts on one drag brace were not torqued to specifications.

2.2.2.1 Excessive axial loads during normal operations

Research was undertaken to determine the loads on the drag brace in flight and the relationship between pre-load in the barrel and nut torque. It was determined that, if the nut threads were normal and they were torqued as specified, the pre-load developed would not be overcome by the normal range of in-service loads. This was supported not only by the engineering studies but also by the lack of similar failures during normal Bell 214ST service. There was no evidence from crews or maintenance records that normal in-flight loads had been exceeded in VH-LAO.

2.2.2.2 Upward bending loads in flight

Information was obtained which indicated that the drag brace is subjected to both axial and bending loads whilst the aircraft is in flight. Additional studies were carried out to determine the effect of bending loads on the stress at the failure position for a full pre-load. The results indicate that the stress at the failure position due to bending loads is small but increases as the pre-load is reduced. If the pre-load is low, any bending loads will have a more important role in contributing to the fatigue failure. In a normal drag brace assembly, the inboard nut transfers bending loads in the barrel through the base of the nut and into the clevis. When the pre-load is overcome by in-flight forces, the nut is no longer bearing on the clevis and the bending loads have to be transferred via a different path.

During normal operations, bending loads have their greatest effect outside the pre-loaded section of the barrel, i.e. on the barrel, shank and clevis. Therefore, if excessive bending loads were the principle reason for the early failure, the failure would not have occurred where it did.

The location of the failure was consistent with moderate—but not extreme—bending loads occurring on an incorrectly pre-loaded drag brace barrel.

2.2.2.3 Thread deformation

In addition to secondary cracks between threads, the metallurgical examination noted some non-uniformities in the nut threads. These included a small variation in pitch and a difference in crest width with the most noticeable being at the location of the primary crack origin in the barrel.

Most of these non-uniformities were probably caused by excessive bearing loads on these particular threads as the fatigue crack in the barrel grew and the loads in the barrel by-passed the crack via the nut.

Nevertheless the possibility of some non-uniformity being present initially in the nut and causing the fatigue crack to initiate was evaluated.

The evaluation could not determine a mechanism which could cause a fatigue crack to initiate at the particular location in the barrel. One submission from an outside party suggested that the non-uniformity may have initiated the fatigue crack, but did not propose any mechanism linking the non-uniformities to the initiation of a fatigue crack at the relevant position in the barrel thread.

Additional work on stress concentrations indicated that it was possible, with the thread variations that were present after the failure, to increase the stress above the normal range in the area of crack initiation. However, the point of maximum stress was still located elsewhere and cracking would be expected to start at a different point on a different thread.

The point pitch variation found was too small to be detectable by normal manufacturing testing procedures.

Inspection of the pitch variations indicated that, whilst they may have resulted in a reduced pre-load at specified nut torque (the actual magnitude of reduction could not be determined), the sequence of thread engagement meant that the point of maximum stress was located on threads other than the one where the crack started.

It was determined that whilst one of several narrow thread crests was located adjacent to the crack origin, the minor variations in thread form and pitch did not contribute significantly to the failure. It is possible that the narrow thread crest did bias the final location of the crack origin; however, it is probable that the crack started for other reasons.

2.2.2.4 Thread witness marks

Specialist evidence indicates that the thread flanks of the inboard nut and the adjacent threads on the barrel did not exhibit detailed witness marks expected following the torque-up process. Evidence was put forward that the lack of marks could have been caused by either of the following reasons:

(a) The thread variations meant that the faces of the threads did not make continuous contact. Therefore the witness marks were not continuous.

(b) The nut was not torqued up correctly.

The thread flanks on the outboard nut and adjacent barrel threads did exhibit the torque-up witness marks. The thread flanks on the undamaged drag brace exhibited witness marks when inspected immediately following the accident but did not exhibit significant torque-up witness marks after it was re-plated and torqued-up during post-accident testing.

Testing indicated that the final torque-up process turns the nut through 60°. If the torque-up process did leave witness marks on the thread face, it would be expected that the barrel thread faces, which showed no variations in thread form, would exhibit regular witness marks over a 60° arc where the faces were bearing on each other. The marks on the thread faces of the inboard nut did not follow this pattern.

The design of the clevis is such that the outboard nut is held in place as the inboard nut is torqued-up. Consequently there is no relative movement between the outboard nut and barrel threads that would normally leave torque-up witness marks. It is probable that the witness marks found on the outboard nut and the undamaged drag brace, before it was re-plated, were caused by a bedding-in process during flight. Consequently the lack of torque-up witness marks is not relevant to determining the failure mode.

2.2.2.5 Low nut torque

Research and testing have eliminated most of the alternatives put forward to date. The only failure model, developed during the investigation and which supports the actual mode of failure, indicates that the most probable reason for the low pre-load between the drag brace nuts was a failure to tighten the nuts to the specified torque during the installation of the new drag braces 398 h prior to the failure.

Submissions by outside parties proposed that the observed non-uniformities in the nut thread pitch and form near the primary crack in the barrel could have initiated the primary crack. However, they did not propose any mechanism which would link the observed variation in thread pitch and form to the initiation of the fatigue crack at the relevant position in the barrel thread. Evaluation by BASI also could not identify any mechanism which would initiate this particular fatigue crack if the nuts were correctly torqued. Consequently, it was determined that on this occasion, failure of the drag brace was probably the result of inadequate tightening of a clevis nut rather than corrosion or other material defects.

2.3 Maintenance aspects

The investigation did not disclose any direct evidence that the maintenance personnel failed to complete the maintenance procedures set out in the operator's maintenance documents. It was determined that the locking wire was in place at the time of failure and the evidence indicated that all personnel believed that all procedures had been carried out correctly and that the aircraft was fully serviceable. The location of the crack inside the inboard nut prevented any of the servicing procedures from disclosing the fatigue crack.

2.4 Survival aspects

Following evacuation of the helicopter, the occupants were subjected to the effects of the fuel in the vicinity. These effects would have been reduced if life rafts had been more readily available. The sea state caused the helicopter to roll inverted immediately after touchdown and the occupants were unable to release the life rafts immediately and had difficulty releasing them later. Nevertheless, the partially inflated life raft, in conjunction with the life jackets worn by the occupants, was adequate in the conditions prevailing.

The crew's radio distress call and subsequent use of the emergency locator beacon allowed the search and rescue system to operate efficiently in locating the survivors. Rescue of the occupants was enhanced by the presence of a dedicated search and rescue helicopter, suitably equipped, at the company's base.

3. CONCLUSIONS

3.1 Findings

1. The pilots were suitably licensed and qualified to undertake the flight, and they were not suffering from illness or incapacity during the flight and accident sequence.
2. The licensed aircraft maintenance engineer who had supervised the installation of the main rotor head was suitably licensed and qualified to conduct the maintenance.
3. The aircraft weight and centre of gravity were within limits.
4. The aircraft had accumulated 2,438 flying hours at the time of the accident.
5. The main rotor head assembly, including drag braces, had been replaced 398 flying hours prior to the accident.
6. The aircraft had not been operated outside of its design limitations since the main rotor head replacement.
7. A fatigue crack initiated in one drag brace shortly after its installation. This was due to inadequate pre-load on the drag brace barrel in the region of the clevis.
8. Available evidence indicates that the inadequate pre-load was probably a result of inadequate torquing of the clevis nuts during rigging of the rotor system.
9. The fatigue crack was located inside the inboard clevis nut and was not visible during routine maintenance inspections.
10. The drag brace was not subject to specific inspection requirements which may have detected the crack.
11. The pilots conducted a successful landing on the water following the failure.
12. The rough sea state induced the helicopter to roll inverted immediately after touchdown.
13. Flotation equipment installed on the fuselage and tail of the helicopter operated properly.
14. An inrush of water and the occupants' haste to evacuate the helicopter prevented the activation of the life raft deployment system from inside the cabin.
15. The survivors encountered difficulty in releasing a life raft because the release on the inverted fuselage was difficult to operate under the water.
16. The search and rescue was quick and effective due to the pilots' distress call, their operation of the portable locator beacon and the availability of a standby search and rescue helicopter.

3.2 Significant factors

1. One drag brace failed following fatigue cracking of the barrel.
2. The fatigue was initiated as a result of inadequate pre-load on the barrel which in turn was probably due to inadequate torque being applied to the clevis nuts.
3. The severe vibration necessitated a forced landing in the open sea.

4. SAFETY RECOMMENDATIONS

The Bureau of Air Safety Investigation recommends that:

1. Bell Textron Helicopter Inc. investigate the installation of an alternate life raft deployment system specifically for use when the helicopter is inverted.

2. Companies involved in the offshore oil industry ensure that all their workers who regularly travel offshore in helicopters, undergo training in a ditching trainer that has the ability to roll over on entry into the water.

3. The Civil Aviation Authority consider a requirement for the installation of an automatically deployed emergency locator transmitter to helicopters engaged in offshore operations.

BASI CONTACTS

basi@dot.gov.au

Brisbane
PO Box 10024
Brisbane Adelaide St
Qld 4000
Telephone: 1800 011 034
Facsimile: (07) 3832 1386
Level 12
Australia House
363 Adelaide Street
Brisbane Qld 4000

Canberra (Central Office)
PO Box 967
Civic Square ACT 2608
Telephone: 1800 020 616
Facsimile: (02) 6247 1290
24–26 Mort Street
Braddon ACT 2612
SITA CBRBACR

Canberra Field Office
24 Mort Street
Braddon ACT 2612
Telephone: 1800 011 034
Facsimile: (02) 6274 6604

Melbourne
Telephone: 1800 011 034
Facsimile: (03) 9685 3611
Level 2
Building 3
6 Riverside Quay
Southbank Vic. 3006

Perth
PO Box 327
Belmont WA 6104
Telephone: 1800 011 034
Facsimile:(09) 9479 1550
Suite2
Pastoral House
277–279 Great Eastern H'way
Belmont WA 6104

Sydney
PO Box Q78
Queen Victoria Bldg NSW 1230
Telephone: 1800 011 034
Facsimile: (02) 9283 1679
Level 7 BT Tower
1 Market Street
Sydney NSW 2000

CAIR
Reply Paid 22
The Manager
CAIR
PO Box 600
Civic Square ACT 2608
Telephone: 1800 020 505
24 Mort Street
Braddon ACT 2612

ACCIDENT INVESTIGATION REPORT B/885/1005

ISBN 0 642 19249 9