Havarikommisjonen for Sivil Luftfart og Jernbane

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REPORT ON THE ACCIDENT 17 NM SW OF STAVANGER AIRPORT 5 NOVEMBER 2002 INVOLVING AS 332 L2 LN-ONI OPERATED BY NORSK HELIKOPTER AS

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ACCIDENT INVESTIGATION BOARD NORWAY (AIBN)
P.O. BOX 213
N-2001 LILLESTRØM
NORWAY

http://www.aibn.no

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REPORT ON THE ACCIDENT 17 NM SW OF STAVANGER AIRPORT 5 NOVEMBER 2002 INVOLVING AS 332 L2, LN-ONI, OPERATED BY NORSK HELIKOPTER AS.

Aircraft type:	Eurocopter AS 332L2
Registration:	LN-ONI
Owner:	LN-ONI Heliair Leasing Limited Ugland House, South Church Street, Georgetown Grand Cayman, Cayman Islands British West Indies
Operator:	Norsk Helikopter AS Postboks 171 4097 Sola Norway
Crew:	2
Passengers:	14
Accident site:	17 NM South West of Stavanger airport SOLA (ENZV), 1,200 ft, 158 kt
Time of accident:	Tuesday 5 November 2002, at 0824 hrs.

All times given in this report are local times (UTC+1), unless otherwise stated.

NOTIFICATION

Accident Investigation Board Norway (AIBN) was notified of the accident on 5 November 2002, at 0905 hrs, by Sola control tower (Sola TWR). Two accident investigators arrived at the accident aircraft parked on the helideck of M/T Navion Anglia to initiate investigations that afternoon.

SUMMARY

LN-ONI was on a regular offshore passenger flight from Sleipner oil field to Stavanger airport Sola. Onboard were 14 passengers and 2 crew. During the descent to 1,000 ft for a visual approach, severe vibrations were encountered.

The crew transmitted a MAYDAY call and informed Sola TWR that they were setting course for two ships which they spotted closer to the coast. The commander landed on the ship closest to the shore line where he landed the helicopter normally on the ship's helideck. After landing it was observed that one main rotor blade (MRB) vibration absorber pendulum weight was missing and that one main rotor blade was severely damaged. The missing weight had penetrated and severed the blade behind the main spar.

The Norwegian Accident Investigation Board (AIBN) investigations have revealed that the direct cause of the vibration absorber pendulum weight loss was fatigue in the shaft (P/N 332 A11-045-20). The fatigue crack had started at a fretting pit and had developed during the course of approximately 100 flight hours. Identified causative factors are pivoting/bending in the spacer (P/N 332 A11-0437-20), fretting on the shaft and spacer, and loss of torque.

The AIBN has identified weaknesses in the basic certification data for the design. The manufacturer had not foreseen the possibility and thereby not analysed the consequence of damage to the MRB following loss of a pendulum weight. This was the second loss in the history of this type of helicopter. Following the first incident where the arm failed, the pendulum arm was redesigned and reinforced. In this last accident it was the pendulum shaft which failed. Since the Finite Element Modelling was not available during the design process it was based on analytical calculations only. There was no considerations of pivoting/bending of the spacer, or fretting or loss of torque. These factors are being considered in the redesign and certification of a modified vibration absorber.

Until a modified vibration absorber is available, flight safety is assured by a mandatory Airworthiness Directive (AD note) which specifies grease lubrications after 100 hrs/3 months, torque check after 300 hrs and overhaul after 2,250 hrs.

AIBN has issued 6 safety recommendations as a result of the accident.

1 FACTUAL INFORMATION

1.1 History of the flight

1.1.1 LN-ONI, with flight no. NOR 431, was on a regular offshore flight from Sleipner oil field to Stavanger airport Sola (ENZV). Onboard were 2 crew and 14 passengers. The commander was at the controls (Flying Pilot, FP) and the first officer was handling navigation and communication (Non Flying Pilot, NFP). The helicopter was on an IFR flight plan to ENZV. Shortly before the accident, NOR 431 had received clearance from Sola Approach to descend from 3,000 ft to 1,000 ft for a visual approach to runway 11 at ENZV.

1.1.2 At 17 NM southwest of ENZV, at an altitude of 1,200 ft and with an indicated airspeed of 158 kt (KIAS), the shaft of the pendulum vibration absorber (Cf. Appendix 1) on the leading edge of the black main rotor blade (MRB) broke off and the weight was cast away. The pendulum weight caused severe damage to the trailing (blue) blade, which again caused severe vibrations in the helicopter.

1.1.3 The commander decided to land immediately and set course for some ships closer to the shoreline. He reduced the airspeed from 158 kt (KIAS) to 100 KIAS which significantly reduced the vibrations. The first officer made a MAYDAY call at time 0824 and informed Sola TWR that they had severe vibrations and control problems. The speed reduction resulted in less severe vibration, and the commander decided to land on a ship. The ship was steering on a northerly heading and had a helicopter deck. The commander landed the helicopter safely on the helideck of Navion Anglia, at a position R242/13DME ZOL, southwest of Sola at 0830 hrs.

1.1.4 Crew members on Navion Anglia were not warned of the approaching helicopter and were unaware of the helicopter before it made the emergency landing on the helideck. The deck was clear and the helicopter crew performed a normal landing and shut down.

1.1.5 The lost absorber weight had penetrated the MRB from the main spar and cordwise through the blade. The total mass loss from the vibration absorber and blade mass resulted in severe imbalance. In addition, the blade lost its rigidity in pitch and lead-lag. This resulted in severe rotor vibrations, which shook the helicopter so much that the crew had problems reading the instruments.

1.2 Injuries to persons

INJURIES	CREW	PASSENGERS	OTHERS
NONE	2	14	0

1.3 Damage to aircraft

1.3.1 Investigations showed that the damage was limited to the loss of the Pendulum Support Weight and damage to the black and blue MRBs. Cf. para 1.12.

1.4 Other damage

None.

1.5 Personnel information

1.5.1 <u>Commander</u>

1.5.1.1 The commander, male 36 years, received his flight training at Swedish Army Flight Battalion in 1993-95. He had flown in Sweden and UAE on helicopter types Eurocopter AS 365, Sikorsky S 76, Bell B 212 and B 414. He was employed by Norsk Helikopter in October 2000 and became Commander in January 2002.

1.5.1.2 The Commander had valid ATPL-H, IR-H and class 1 medical licences with no restrictions. His medical licence expired on 1 October 2003. Last OPC (Operational Proficiency Check) was on 24. May 2002. His last survival training was on 19 January 2001. The commander had attended a CRM (Crew Resource Management) course on 13 May 2001.

1.5.1.3 The Commander's total flight time was:

FLYING EXPERIENCE	ALL TYPES	ON TYPE
LAST 24 HOURS	2:40	2:40
LAST 3 DAYS	5:00	5:00

LAST 30 DAYS	43:30	43:30
LAST 90 DAYS	119	119
TOTAL	4,476	930

1.5.2 First officer

1.5.2.1 The first officer, male 38 years, received his flight training at European Flight Center at Torp, Norway in 1996. He had flown for 7 years on helicopter types R 22, R 44 and AS 332. He became an employee of Norsk Helikopter in 2001.

1.5.2.2 The first officer had valid CPL-H, IR-H and class 1 medical licences with no restrictions. His last medical examination was on 1 November 2002. Last OPC was on 4 August 2002. His last survival training was on 14 September 2001. The first officer had attended a CRM course on 5 October 2001.

1.5.2.3 The first officers total flight time was:

FLYING EXPERIENCE	ALL TYPES	ON TYPE
LAST 24 HOURS	5:25	5:25
LAST 3 DAYS	9:20	9:20
LAST 30 DAYS	53:40	53:40
LAST 90 DAYS	143	143
TOTAL	1,685	495

1.6 Aircraft information

1.6.1 General

Eurocopter (EC, previously Aerospatiale, AS) AS 332L Super Puma Mk1 helicopter was introduced into offshore operations in 1982. The AS 332L2 Super Puma Mk2 which is an upgraded version of the AS 332, came into offshore operations in 1993. AS 332L2, S/N 2500, LN-ONI, was built in 1999. This helicopter model is equipped with two Turbomeca Makila 1A2 turbine engines. Maximum take-off mass is 9,300 kg. The helicopter is operated by two pilots and is able to carry 19 passengers in offshore operations. At the time of the accident, its total flying time was 5,513:28 hrs, with 32:04 hrs since its 75 hrs inspection. The aircraft was serviceable before the flight, with no noted discrepancies which made the aircraft unserviceable.

1.6.2 Vibration Absorber

1.6.2.1 The vibration absorber consists of two pendulum weights mounted on a common shaft at the main rotor blade root. One weight is on the leading edge of the blade cuff, and the other is mounted on the trailing edge. Cf. Appendix 1. The shaft is mounted on bearings and the weights are allowed to oscillate freely. With the rotor stationary the weights hang vertically. As the rotor RPM increases, the weights are lifted under influence of centripetal forces and are kept at an angle depending on RPM and vibrations. During flight the pendulum weight oscillates at ± 35° in relation to the blade. Hence the shaft is subjected to rotational (torsional) bending forces. The purpose is to reduce MRB vibrations by dynamic balancing.

1.6.2.2 According to Eurocopter the Vibration Absorber Assembly (P/N 332 A11-0460-02, S/N 240) had a total operating time of 5,650 hrs. Normal overhaul interval was 2,250 hrs. The last overhaul was performed at 1,157 hrs due to a bearing replacement. AIBN has noted that no vibrations absorbers of this type reached their specified overhaul time interval of 2,250 hrs.

1.6.2.3 Based on the information from the operator's records, the AIBN investigations indicate that the vibration absorber S/N 240 was removed from AS 332L2, LN-ONH (S/N 2488), on 10 November 2001 due to bearing replacement. The total running time of S/N 240 was then 4,474:31 hrs and time since overhaul was 2,234:44 hrs. On 9 January 2002 the overhauled vibration absorber S/N 240 was released for service. On 27 January 2002 the overhauled S/N 240 was installed on aircraft AS 332L2, LN-ONI, (S/N 2500) at a helicopter total flight time of 4,333:24 hrs, and with 0 flight time since overhaul. This indicates that the pendulum weight was last overhauled at a total time of 4,474:31 hrs and that it had operated for 1,180:04 hrs (5,513:28 – 4,333:24) since overhaul. The vibration absorber (S/N 240) had a total running time of 5,654:35 hrs when it failed. Hence, there is a discrepancy between the EC records and AIBN estimates (based on the operators records) of a total running time of 4:35 hrs for vibration absorber S/N 240.

1.6.2.4 Vibration absorber inspection methods

Before the accident

- Daily check after last flight
- Check every 150 flight hours
- Overhaul at 2,250 flight hours

After the accident (Alert Telex 05.00.58 R2 and 05.00.60)

- Removal of vibration absorber for complete one-time inspection
- Magnetic particle inspection of the shaft
- If fretting micro-cracks observed – reject the shaft
- Tightening torque check every 300 flight hours
- Greasing every 100 flight hours or 3 months

1.6.2.5 Vibration absorber flight restrictions

Before the accident

- None

After the accident and until Alert Telex 05.00.60 was C/W (Alert Telex 01.00.68)

- Limit aircraft speed to130 kt and limit bank angle to 30º.

1.6.2.6 Modified vibration absorber

General

As a result of the accident, EC initiated a design process for new vibration absorber parts.

Redesigned shaft

The redesigned parts included a longer inner washer of 25 mm length. Cf Appendix 9. This will:

- Give better contact pressure distribution without pivoting.
- Prevent fretting wear.
- Produce lower stress levels under loads.

The shaft will be hard deposited under the bearing and inner washer. This will give:

- Fretting prevention.

The inner washer will be shrunk on the shaft, the tightening torque will be optimised and the bearing reliability will be improved.

1.6.3 Tightening torque

The AIBN investigations have revealed that actual tightening torque values on the plug (P/N 332A11-0451-21, cf. Appendix 1/2) installed on fleet aircraft differed from EC's specified torque values of 90-100 Nm (cf. para 1.18.2). These values were recorded on installed vibration absorbers and AIBN has no information indicating that the operator had used a wrong torque value at the installation of S/N 240. Norsk Helikopter has informed AIBN that they used the EC specified torque values for installation. AIBN has not been able to establish why the actual torque values differed from the EC specified values.

1.6.4 Emergency procedure for dealing with severe rotor vibrations

The AS 332L2 Aircraft Flight Manual does not contain an emergency procedure for dealing with severe rotor vibrations. EC has informed AIBN that an airspeed of 100 KIAS will reduce rotor vibrations to a minimum.

1.6.5 Fuel

The helicopter took off from Sleipner with 900 litres of JET A1 fuel onboard. Estimated fuel on landing at Sola was 440 kg. The fuel load at the emergency landing was approximately 450 kg.

1.6.6 Mass and balance

The take-off mass from Sleipner oil field was 8,463 kg. The centre of gravity was in the aft range, but still well forward of the aft limit.

1.7 Meteorological information

1.7.1 TAF

The forecast weather at ENZV for the flight period was:

TAF ENZV 050500Z 050615 15012KT 9999 FEW015 BKN030 TEMPO 1215 RA BKN012=

1.7.2 METAR

Actual weather at Sola at time 0820 was:

METAR 050720Z 140/09KT 9999 FEW020 BKN035 05/M01 Q1022 NOSIG

1.7.3 General

The weather conditions at the time of the accident were good, with a visibility of more than 10 km, wind from 30º 20-25 kt, scattered clouds at 2,000 ft and broken cloud cover at 2,500 ft. The sea state was of the order of 6 Beaufort with a wave height of 3 metres.

1.8 Aids to navigation

Normal

1.9 Communications

Normal

1.10 Aerodrome information

Not applicable

1.11 Flight recorders

1.11.1 Cockpit Voice Recorder and Flight Data Recorder

The helicopter was equipped with a Penny & Giles combined Cockpit Voice and Flight Data Recorder, (CVFDR, P/N 2000D51521-010-112, S/N 1045-09-96). The recorders were downloaded at the Aircraft Accident Investigation Branch' facilities at Farnborough, UK. The recorded data was of good quality and very useful to the investigation.

1.12 Damaged parts information

1.12.1 Vibration Absorber Assembly

1.12.1.1 Missing parts

The Vibration Absorber Assembly (P/N 332 A11-0460-02, S/N 240), on the black blade was missing the leading edge part of the shaft (P/N 332 A11-0450-20, which had broken off. Along with the missing part of the shaft was the Support Weight (P/N 332 A11-0450-20) and all the parts outside of the Bearing. Cf. Appendix 1.

1.12.1.2 Failure process

The AIBN's investigations have revealed that the cause of the pendulum weight loss was fatigue in the steel shaft (P/N 332 A11-045-20). The fatigue crack had started at a fretting pit mark and had developed during a period of approximately 100 flight hours. Identified causative factors were pivoting/bending of the spacer (P/N 332 A11-0437-20) and the shaft, loss of torque, and fretting on the shaft and spacer.

1.12.2 Main Rotor Blades

The Pendulum Support Weight had first made contact with the upper side of the black MRB (S/N 305). It then struck the following blue MRB (S/N 140) on the underside close to the leading edge. The black blade had strike damage on top of the blade just outboard of the blade root. The blue blade had been hit by the pendulum support weight under the leading edge at about 3/4 of blade length from the root, at blade station 2530. The pendulum weight made a dent in the stainless steel leading edge strip and then penetrated the blade structure aft of the main spar, leaving the spar intact. It had continued cordwise through the blade towards the trailing edge spar, which was cut. The MRB is built as a torsion box. With a cut trailing edge the MRB has lost its rigidity in torsion. Cf. Appendices 10-16. Through its path, the weight ripped out 280 g of blade mass. The total mass loss and the loss of built in rigidity in pitch and lead-lag resulted in severe rotor vibrations at 158 KIAS (Cf. §1.15.4.1). The speed reduction to 100 KIAS reduced the blade loadings and vibrations to approximately half of the initial values.

1.13 Medical and pathological information

Not applicable.

1.14 Fire

Not applicable.

1.15 Survival aspects

1.15.1 Continued flying

In this accident, the lost Support Weight damaged an MRB aft of the main blade spar. Hence the spar strength was intact and supported its share of blade lift. However, due to mass and rigidity loss, the blade motion caused severe vibrations which were capable of damaging to the whole aircraft. Due to the crew’s actions of reducing speed to 100 KIAS, the MRB loading and vibrations were reduced to an endurable level, enabling the crew to land at a nearby ship with a helideck.

1.15.2 Emergency landing (ditching) in the sea

The helicopter was fully equipped for offshore operations and contained the required survival equipment. The sea state was relatively rough with 3 metres wave height. However, the AS 332L/L1 has proved to be a stable aircraft when floating on its emergency floatation gear. The floating characteristics of the L2 version are not considered to be very different. Based on experience from previous helicopter ditchings in the North Sea, the AIBN considers the survival aspects following a ditching at the time of the accident to be positive.

1.15.3 Modified Automatic Dependent Surveillance (M-ADS)

The helicopter was equipped with a Modified Automatic Dependent Surveillance (M-ADS) system. The aircraft plot is displayed on a combined radar and ADS (RaADS) display in the ATCC. Cf. Appendix 18. This surveillance system tracks the offshore helicopters outside of radar coverage. In case the Commander had decided to make an emergency landing in the sea, this system would have indicated the position with normal GPS accuracy. This would have been a great enhancement during a Search and Rescue (SAR) operation.

1.16 Tests and research

1.16.1 General

The AIBN has consulted the Norwegian Defence Laboratories (FLO/LHK) and Eurocopter Materials Laboratory regarding laboratory tests and analytical investigations. After completion of investigations at the LHK laboratories the parts were sent to EC for further tests and analysis.

1.16.2 Vibration Absorber

1.16.2.1 Defence Laboratories (FLO/LHK)

The results of the investigations into the failed vibration absorber assembly at the Defence Laboratories, Chemical and Materials Technology, are covered by report no. 021111.09, dated 19 November 2002:

> *"From the obtained results the following conclusions can be drawn:*
>
> *The shaft fracture is due to fatigue, most likely initiated from fretting damages at the outer diameter.*
>
> *The fretting damages are also observed on the inner washer towards the shaft interface.*
>
> *The raceway of the outer bearing ring show severe spalling damages, and is believed to have been close to a total break down.*
>
> *The base material quality of the investigated parts is as expected for the system in question.*
>
> *At this point the true cause for the Vibrator absorber assy failure is not established, however it is obvious that the system has been subjected to abnormal cyclic loadings at the failed area, resulting in the initiation of the fretting and subsequent fatigue damage".*

The AIBN received from the operator a similar absorber shaft with possible fretting damage in the same area as the failed absorber shaft. The AIBN wanted to investigate possible fretting at the area corresponding to the failed area of the shaft covered by the report no. 021111.09. These results are covered by the report 021202.02, dated 3 December 2002:

> *"It is concluded that fretting has occurred on the shaft surface along a 1.2 mm wide band. The fretting depth was measured to be of the order of 10 µm. In addition*

some pits could be observed on the fretted surface. The largest pitting depth observed in the fretted area was measured to extend 7 µm into the base material".

1.16.2.2 Eurocopter investigation of failed vibration absorber individual parts

The failed and recovered parts of the vibration absorber were investigated at the Eurocopter Materials Laboratory. The results are presented in the report OIQL, No. 3296/2002:

"*The transverse failure of the rotor blade vibration absorber shaft is a progressive bending-fatigue failure.*

The fatigue starts on the external surface of the shaft, in an area of fretting caused by contact between the spacer and the shaft.

This failure, on the leading edge of the shaft, is located at the end of the bearing surface of the 25g6 diameter, at 1.4 mm from the radius adjacent to this 25 diameter.

From the dimensional point of view, no edge was observed at the 25g6 diameter nor other type of fault likely to have contributed to the failure.

The other forms of damage observed on the spacer and part of the shaft in our possession are limited to more or less extended fretting areas of variable degrees according to the areas considered. The most significant of these is the wear seat caused by the fretting from 0.01 to 0.04 mm deep.

To be also specified, the fracture surface showed 50 main macro marks. If we accept that these stop lines represent the rotor stops and that the average between two rotor stops carried out by the aircraft is approximately 2 hours (value given by analysis of the aircraft log book), the propagation time of the failure is approximately 100 hours.

The metallurgical quality of the part is not implicated."

1.16.2.3 Eurocopters investigation and analysis of the failed vibration absorber shaft

Investigation

EC's investigation of the failed shaft shows that the crack initiation on the shaft was at the contact with the inner washer, as a result of micro-cracks due to fretting. The fatigue failure was caused by rotational bending. There was no geometry or material defect involved. Fretting was observed on all contact areas. Cf. Appendix 7.

Calculations

EC calculated the shaft failure mode by using Finite Element Modelling. Cf. Appendix 8. It was shown that pivoting of the washer caused fretting wear. This resulted in loss of tightening torque. It was demonstrated that with the loss of 80% tightening torque, a fatigue failure could be simulated.

1.16.3 Modified vibration absorber analyses

1.16.3.1 General

As a result of the accident EC initiated a design process for modified vibration absorber parts. Cf. para 1.6.2.6.

1.16.3.2 Modified shaft

The modified parts include a longer inner washer to improve pressure distribution, lower strain levels and prevent fretting. The inner washer will be shrunk onto the shaft, the tightening torque will be optimised and the bearing reliability will be improved.

1.16.3.3 Analytical calculations of the shaft

Static strength margin

Analytical calculations show that the minimum static margins are given by the over-speed at limit (1 x limit load) and ultimate loads (1.5 x limit load).

Fatigue strength margin

In fatigue the infinite safe life has been demonstrated at f/3 (180 Mpa).

1.16.3.4 Numerical calculations of the shaft and housing

By using Finite Element Modelling the equivalent cyclic stress has been numerically calculated at various tightening torque levels from 100% down to 20%. The results show that even after a complete loss of torque, the stress level is low enough to guarantee safety.

The numerical calculations show that:

- In static loading the margin is > 100% at limit loading.
- In cyclic loading the fatigue margin is > 100% at ultimate loading.
- In cyclic loading, the fatigue infinite safe life has been demonstrated at f/3 (33.33 Mpa).

1.16.4 Main Rotor Blade

The AIBN consulted Eurocopter Materials Laboratory regarding investigations on the damaged main Rotor Blade (MRB). The blade airfoil section is shown in Appendix 13 and the damaged blade sections are shown in Appendix 16.

1.16.4.1 Eurocopter

The initial investigations into the damaged MRB show:

- *The total mass loss of vibration absorber and blade mass loss was 6.5 kg. This resulted in a total imbalance of 5,500 N, which resulted in a vibration level of 5.12 IPS, or 0.37G in 1 Ώ (1 pr. rev).*

Static and dynamic calculations at blade section 2430 to determine the static strength and fatigue strength of the damaged blade, show that:

- *The results relate only to the spar (single part remaining intact).*
- *The static results show a margin of 82% concerning the ultimate load.*
- *The results for high and low cycle fatigue give a safe life of >1,000 hrs.*
- *The results do not take into account any imbalance effects.*

This and previous experience of blades having undergone significant damage confirm the capacity of the blades to assure landing after a few minutes of flight.

However, EC has indicated to the AIBN during a meeting that these calculations are very uncertain, as the exact effects of lost rigidity and increased vibrations are impossible to calculate to a high degree of accuracy.

1.17 Organisational and management information

1.17.1 Norsk Helikopter AS was established in 1993. The company has a JAR OPS 3 Aircraft Operating Certificate (AOC) for VFR and IFR helicopters of the types Sikorsky S-76C and Eurocopter AS 332/AS 332L2. The company also had a JAR 145 approval for the same aircraft types.

1.17.2 At the time of the accident, the company was operating six AS 332L/L1/L2 and two S-76C+ in the offshore transport, shuttle and search and rescue services, and had 149 employees. The company's main operating base is Stavanger Airport Sola. It also operates out of Bergen airport, Flesland (ENBR), Kristiansund airport, Kvernberget (ENKB), and Brønnøysund airport, Brønnøy (ENBN). In addition the company has SAR helicopters based offshore at Frigg and Draugen oil fields.

1.18 Additional information

1.18.1 <u>Missing information in the parts catalogue</u>

During the investigations the AIBN has uncovered missing information in the AS 332 MK2 Illustrated Parts Catalogue (IPC). In Fig. 02 in IPC AS 332 MK2, 62-10-00, page 0, date 2000.09.30, Absorber Assembly, Vibration, item 130, Washer (P/N 332A11-0437-20), on one side of the absorber is missing from the drawing, and from the figure’s itemised list. Cf. Appendices 1 and 2.

1.18.1.1 Missing installed washer in vibration assembly

During the investigations, the AIBN has been informed of an incident where an operational vibration absorber failed as a consequence of a missing washer (P/N 332A11-0437-20). There may be a connection between the missing washer and the missing information in the IPC.

1.18.2 <u>Operators’ use of torque values</u>

The EC's torque requirement on the retaining plug (P/N 332A11-0451-21, Cf. Appendices 1/2) on the vibration absorber was 90-100 Nm. Investigations made by EC after the accident, show that the measured torque values reported by several operators varied between 62 Nm (under-torque) and 165 Nm (over-torque). Furthermore, the investigations show that only 52.5% of the inspected vibration absorbers had the correct torque values. 47.5% had torque values that were either too low or to high. The same investigation showed that 17.5% of the vibration absorbers had no fretting. 37.5% had some fretting and 45% had excessive fretting, causing the shafts to be replaced. The AIBN has not been able to establish the cause for the erroneous tightening torque values.

1.18.3 Operator's standard procedures

The AIBN investigations have revealed that operators standard procedures differ. Norsk Helikopter's procedure for enroute descent is to maintain the collective setting at the cruise setting, thereby allowing the airspeed to increase during enroute descent. Hence the airspeed in this case was 158 KIAS at the failure point. This is a relatively high airspeed which causes major rotational loading on the vibration absorber. Another Norwegian operator, CHC Helikopter Service, uses a different procedure where the collective setting is reduced during the en route descent. Hence, cruise true airspeed is maintained during the descent. The significance of this difference is that in the Norsk Helikopter procedure, the cyclic loading on the vibration absorber is increased during the descent. For this reason, the vibration absorbers in this helicopter fleet may be subjected to higher cyclic loading than average. EC's investigations show that there were more fretting marks on vibration absorbers from Norsk Helikopter than on vibration absorbers from CHC Helikopter Service. This type of vibration absorber is unique to the L2 version of the AS 332 and does not affect AS 332L/L1 helicopters.

1.18.4 Emergency procedure for severe vibrations

The AS 332L2 Flight Manual does not contain an emergency procedure for dealing with severe vibrations. Such vibrations may be caused by faults in the main rotor blades, tail rotor blades, transmission system and accessories. EC has confirmed to the AIBN that an airspeed of 100 KIAS is the optimal airspeed for reducing rotor vibrations. This will result in the lowest torque values and lowest blade loading. This also approximates to the endurance speed of the helicopter.

1.19 Useful or effective investigation techniques

During the EC's investigations, Finite Element Modelling has been used to analyse the stress levels in the shaft. This technique was first introduced at EC in 2000, and was not available to EC at the time the vibration absorber was designed in 1990.

2 ANALYSIS

2.1 Vibration absorber failure

2.1.1 Norwegian accident investigation board (AIBN) investigations have revealed that the direct cause of the pendulum loss was fatigue in the steel shaft (P/N 332 A11-045-20) due to rotational bending loads. The fatigue crack had started at a fretting pit mark just at the edge of the bearing and had developed during the course of approximately 100 flight hours. Identified causative factors are pivoting/bending of the spacer (P/N 332 A11-0437-20) and the shaft, resulting in play (gaps) between the washer and the shaft. This results in fretting, which again causes the development of micro-cracks and higher stress levels. Furthermore, it results in loss of torque on the retaining nut (plug) and more fretting on the shaft, washer and bearing race. The propagation of the micro-cracks resulted in the development of the fatigue macro-crack.

2.1.2 When the shaft broke, the absorber weight with the accompanying parts separated from the mounting and was cast outward and initially hit the top of the black blade. It continued outward and hit the following blue blade. The weight penetrated and cut the blue MRB aft of the main beam.

2.1.3 The combined mass loss of the vibration absorber and the blade mass caused a major imbalances in the rotor system. This imbalance alone created severe rotor vibration. In addition, the partially severed blade had lost its rigidity in pitch and lead-lag and was partially uncontrollable. This amplified the vibrations, which alarmed the crew and forced them to make an emergency landing on a ship which had a helideck.

2.2 Main Rotor Blade residual strength

2.2.1 The EC investigations indicate that the residual strength of the damaged MRB was very uncertain. Based on the available information and analysis (Cf.para 1.15.4.1), the AIBN considers an immediate landing was the best possible course of action by the crew.

2.3 Survival aspects

2.3.1 The damage to the blue main rotor blade was extensive. The AIBN's conclusion is that continued airworthiness of the helicopter was very uncertain and that the crew made the best decision for survival. The AIBN commends the crew for its good judgement and airmanship in dealing with this extreme emergency.

2.3.2 The path of a lost weight is however, arbitrary. Therefore survival aspects must also consider the scenario where of the weight hitting a tail rotor blade (TRB). in such a scenario, an autorotational landing or ditching may be considered.

2.3.3 The weather was generally good but the sea state was somewhat rough with a wave height of 3 metres. Continued flying to the shoreline would have taken another 10 minutes. Due to the uncertainty regarding the state of the blue blade, the AIBN considers a ditching would have been the best alternative, if no offshore landing site had been available.

2.4 Maintaining airworthiness

EC, French and Norwegian aviation authorities took immediate actions in order to maintain the continued airworthiness of the fleet after the accident. EC issued Alert Telexes which detailed new inspection and repair procedures.

2.5 Initial certification

The investigations have revealed that during the design process in 1990, Finite Element Modelling was not used by EC. Hence, the initial calculations did not include torsional loads. These loads were discovered during measurements after the first failure of the vibration absorber. Nor was damage to the main rotor blades or the tail rotor blades considered in the failure mode and analysis in the design of the vibration absorber.

2.6 Manufacturers modification

The AIBN supports Eurocopter's decision to initiate a design process for a modified vibration absorber as a direct consequence of the accident. Cf. para 1.15.3.

2.7 Emergency procedures

2.7.1 The speed reduction to 100 KIAS reduced the blade loadings and vibrations to a point where the risk of further damage was reduced to a minimum. The crew exercised good airmanship and handled the emergency in a professional manner, which reduced any further risks to a minimum.

2.7.2 The Aircraft Flight Manual (AFM) does not contain a pilot procedure for handling severe vibrations. This accident illustrates the immediate effect of reducing airspeed to 100 KIAS. This speed produces minimum loadings in the rotor system and reduces the vibrations to a minimum. The AIBN suggest that an emergency procedure for severe vibrations may be to reduce the airspeed to 100 KIAS.

2.8 Missing information in the Illustrated Parts Catalogue

The AIBNs investigations have uncovered a missing item and part number in the AS 332 MK2 IPC. The missing item is the washer (spacer) involved in the accident. The missing item in the IPC was of no consequence in this accident, but the present investigations uncovered another occurance in which a vibration absorber failed as a result of a missing spacer as mentioned above. The AIBN will not dismiss the possibility that the failure to install the washer may have been a result of the washer being missing from the IPC.

2.9 Operators use of torque values

The AIBN’s investigations have revealed that, among operators, the torque values on the vibration absorbers varied extensively and were often outside the manufacturers specifications. Loss of torque results in more pivoting/bending of the washer and shaft, giving more play and loss of contact. This produces further fretting and micro-cracks. The AIBN has not been able to establish the cause of these deviant torque values among the operators.
Cf. para 1.17.2.

2.10 Operator standard procedures

Norsk Helicopter AS is using a flight procedure that increases airspeed and the cyclic loading on the vibration absorbers during the descent phase. The AIBN considers that this procedure may have shortened the endurance of the vibration absorbers. Eurocopter confirms that there was more fretting on vibration absorbers from Norsk Helikopter than on those from CHC Helikopter Services. Based on this evidence Norsk Helikopter should reconsider its use of the constant torque descent procedure. Cf. para 1.17.3.

2.11 Overhaul interval time

AIBN’s investigation has revealed that no vibration absorbers reach their specified overhaul interval of 2,250 flight hrs. This may be an indication that the overhaul interval is set too optimistic.

2.12 Modified Automatic Dependent Surveillance (M-ADS)

LN-ONI was equipped with a Modified Automatic Dependent Surveillance system. This accident highlights the great value of the M-ADS system for SAR operations. The system tracks the aircraft down to sea level outside of radar coverage by help of satellite communication. Inside radar coverage the system uses radar data for tracking. Cf. Appendix 18.

3 CONCLUSIONS

3.1 The aircraft was serviceable before the accident.

3.2 The mass and balance were within limits.

3.3 The crew was certified for the mission.

3.4 One vibration absorber on Black blade failed during descent through 1,200 ft at an airspeed of 158 KIAS.

3.5 The failure was a result of a broken shaft, resulting in the loss of the shaft with the complete pendulum weight assembly.

3.6 The shaft failed as a result of fatigue caused by cyclic rotational loading from low stress levels. The reason the shaft failed was 75% fatigue and 25% static overload.

3.7 The fatigue crack was initiated by fretting on the external surface of the shaft, caused by contact between the spacer and the shaft. The cause of the initial fretting may be a result of excessively low torque at the time of installation and further loss of torque because of pivoting and bending due to torsional loads.

3.8 The cause of the fretting was the pivoting and bending of the spacer. This resulted in a play between the spacer and the shaft. The pivoting and bending resulted in higher stress levels, loss of torque and more fretting. The fretting initiated micro-cracks which triggered the fatigue macro-crack which developed during the course of approx. 100 hrs.

3.9 The vibration absorber had a total of 5,650 hrs of operation and had been overhauled at 1,179 hrs when a bearing had been changed. The vibration absorber’s normal overhaul time was 2,250 hrs.

3.10 The specified overhaul time interval for the vibration absorbers were not reached during operations.

3.11 The lost weight together with component parts hit blue blade at station 2530, cut through the blade cordwise and cut the trailing edge. This severely reduced the blade rigidity.

3.12 The total mass loss on the vibration absorber and blade mass of 6.5 kg resulted in a total imbalance of 5,500 N. The imbalance resulted in severe rotor vibrations of 5.12 inches per second (IPS) or 0.37 G in once per revolution.

3.13 The severe vibration caused the crew to make an emergency landing on a ship 12 NM off the coast. The crew reduced the airspeed to 100 KIAS which reduced the vibration level considerably.

3.14 The AFM did not contain an emergency procedure for severe rotor vibrations.

3.15 The investigations uncovered a missing item in the Illustrated Parts Catalogue. This may have caused another vibration absorber on a different helicopter to be wrongly assembled. This was however, not a factor in this accident.

3.16 The investigations have uncovered during checks among several operators after this accident, that the manufacturer’s specified torque levels have not been adhered to by various operators. EC has registered both gross over-torque and under-torque. This may be a result of the torque changes during operations.

3.17 The AIBN investigations revealed that Norwegian operators use different flight procedures during descent, where the Norsk Helikopter’s procedure subjects the vibration absorbers to higher loading during descent.

3.18 The investigation indicates that there was more fretting on Norsk Helikopter’s vibration absorbers than on those of CHC Helikopter Services.

3.19 Eurocopter has in progress a new vibration absorber design which is believed to prevent any recurrence of this type of failure.

3.20 LN-ONI was equipped with a M-ADS system. This accident highlights the great value of the system installed in offshore helicopters.

4 SAFETY RECOMMENDATIONS

The AIBN recommends that CAA-N and DGAC evaluate the requirement for:

4.1 Eurocopter to include an emergency procedure for severe rotor vibrations in the AS 332/L2 Aircraft Flight Manual. (SL recommendation no. 31/2005)

4.2 Eurocopter to revisit the design process and failure mode and analysis for the design and certification of the AS 332L2 MRB vibration absorber, and includes the failure scenario of damage to the main and tail rotor blades as a consequence of loss of a vibration absorber.(SL recommendation no. 32/2005)

4.3 Eurocopter to revise the AS 332L2 IPC to include the missing washer (P/N 332A11- 0437-20) on the vibration absorber. (SL recommendation no. 33/2005)

4.4 Eurocopter to evaluate the information in the AS 332L2 Maintenance Manual regarding the importance of using and maintaining the specified torque levels on the MRB vibration absorber. (SL recommendation no. 34/2005)

4.5 Eurocopter to evaluate the present overhaul interval of 2,250 hrs for the vibration absorbers. (SL recommendation no. 35/2005)

4.6 Eurocopter to include a recommended operating procedure in the AS 332L2 Aircraft Flight Manual for use during descent. (SL recommendation no. 36/2005)

APPENDICES

1. Illustrated Parts Catalogue AS 332 MK2, page 0
2. Illustrated Parts Catalogue AS 332 MK2, page 1
3. Definition of the blade vibration absorber
4. Investigation of the shaft - observations of the crack
5. Fatigue crack initiation and propagation
6. Finite Element Modelling - Loss of tightening torque
7. Finite Element Modelling/Calculation results - Fretting/wear
8. Finite Element Modelling/Calculation results - Propagation of possible fatigue fretting micro-cracks
9. Terminal actions - Modification project - modified vibration absorber
10. Main rotor blade 332 A 11 0041 - Blade definition
11. Main rotor blade 332 A 11 0041 - Blade definition - Attachment Part
12. Main rotor blade 332 A 11 0041 - Blade definition - Airfoil Section 1
13. Main rotor blade 332 A 11 0041 - Blade definition - Airfoil Section 2
14. Investigation of the main rotor blade 332 A 11 0041 no. 140 - underside
15. Investigation of the main rotor blade 332 A 11 0041 no. 140 - top side
16. Investigation of the main rotor blade 332 A 11 0041 no. 140 - blade sections
17. LN-ONI on helideck of Navion Anglia
18. RaADS plots

ABBREVIATIONS

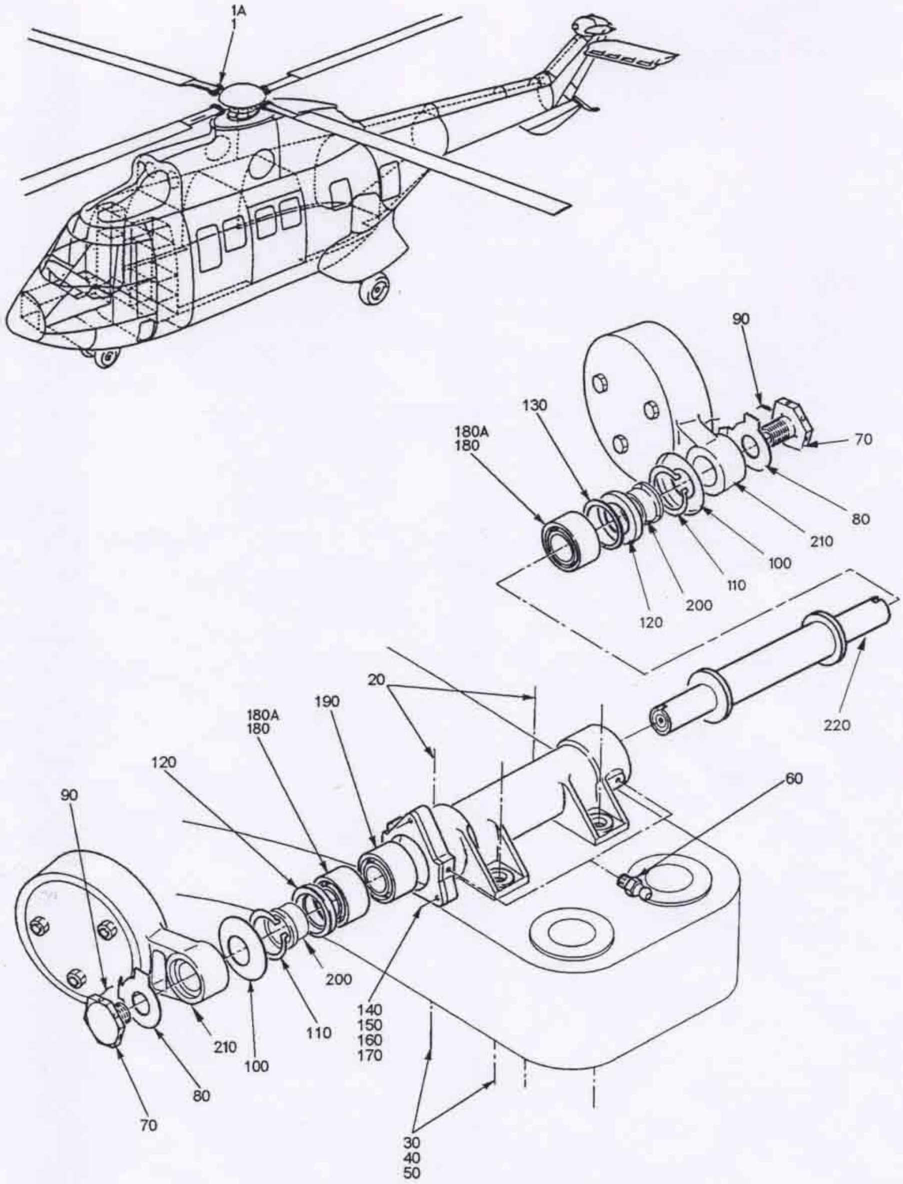
AAIB	Aircraft Accident Investigation Branch (UK)
AIBN	Accident Investigation Board Norway

AOC	Air Operating Certificate
AS	Aerospatiale
ATPL-H	Air Transport Pilot Licence – Helicopters
ATCC	Air Traffic Control Centre
CPL-H	Commercial Pilot Licence - Helicopters
CRM	Crew Resource Management
CVR	Cockpit Voice Recorder
C/W	Completed With
EC	Eurocopter
FDR	Flight Data Recorder
FLO	Forsvarets Logistikk Organisasjon
IFR	Instrument Flight Regulations
IR-H	Instrument Rating – helicopters
IPS	Inches Per Second
JAR	Joint Aviation Regulations
KIAS	Knots Indicated Air Speed
LHK	Luftforsvarets Hovedverksted Kjeller
M-ADS	Modified Automatic Dependent Surveillance
METAR	Meteorological Aerodrome Report
MRB	Main Rotor Blade
NOR	Norsk Helikopter
OPC	Operational Proficiency Check
OPS	(JAR) Operations
P/N	Part Number
RaADS	Radar and ADS display
SAR	Search and Rescue
S/N	Serial Number

TAF	Terminal Area Forecast
TRB	Tail Rotor Blade
TWR	Control tower
UAE	United Arab Emirates
VFR	Visual Flight Regulations

ACCIDENT INVESTIGATION BOARD NORWAY (AIBN)

Lillestrøm, 7. Juni 2005



ABSORBER ASSY,VIBRATION
FIG. 02

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FIG. ITEM	FSCM	MANUFACTURER PART NUMBER	DESCRIPTION 1 2 3 4 5 6 7	QTY PER ASSY	
02 1	F0210	332A11-0460-02	ABSORBER ASSY,VIBRATION 2338 2348 2366 2380 2388 2390 2393 2395-2396 2398 AFTER AMENDMENT 07 40 641	REF	N
1 A	F0210	332A11-0460-02	ABSORBER ASSY,VIBRATION 2455 2467 2471 2474 2477 2484 2488 2493 2500 2503-2504 2998 AFTER AMENDMENT 07 40 641	REF	N
20	F0210	332A11-0467-20	. SCREW	4	N
30	F0210	332A11-0468-20	. WASHER	4	N
40	F5442	ASNA0045-120BCL	. NUT	4	N
50	F0111	23310CA020025	. PIN,SPLIT	4	N
60	F0111	L22811-1	. LUBRICATOR	2	N
70	F0210	332A11-0451-21	. PLUG	2	N
80	F0210	332A11-0476-20	. LOCKPLATE AFTER AMENDMENT 07 40 641	2	N
90	I9005	EN3628-080	. WIRE,LOCKING	AR	N
100	F0210	332A11-0439-20	. FLANGE	2	N
110	D2558	FK7DSB42	. RING	2	N
120	F0563	GR32X42X4	. SEAL,LIP	2	N
130	F0210	332A11-0436-20	. WASHER	1	N
140	F0112	22129BE050026L	. SCREW	3	N
150	F0111	23112AG050LE	. WASHER	6	N
160	F5442	ASNA0044-050BCL	. NUT	3	N
170	F0111	23310CA010015	. PIN,SPLIT	3	N
180	F0563	NA4905BIR	. NEEDLE BEARING APPLIC. FOR NHA 1	2	N
180 A	F0270	NA4905R2000	. BEARING,NEEDLE APPLIC. FOR NHA 1A AFTER AMENDMENT 07 40 640	2	N
190	F0270	71905HDFJ94	. BEARING,SKEW-ANGLE ROLLER	1	N
200	F0210	332A11-0447-20	. BEARING,SEAL	2	N
210	F0210	332A11-0474-00	. SUPPORT WEIGHT,EQUIPED AFTER AMENDMENT 07 40 641	2	N
220	F0210	332A11-0450-20	. SHAFT	1	N
		332A11-0437-20	SPACER		

- ITEM NOT ILLUSTRATED

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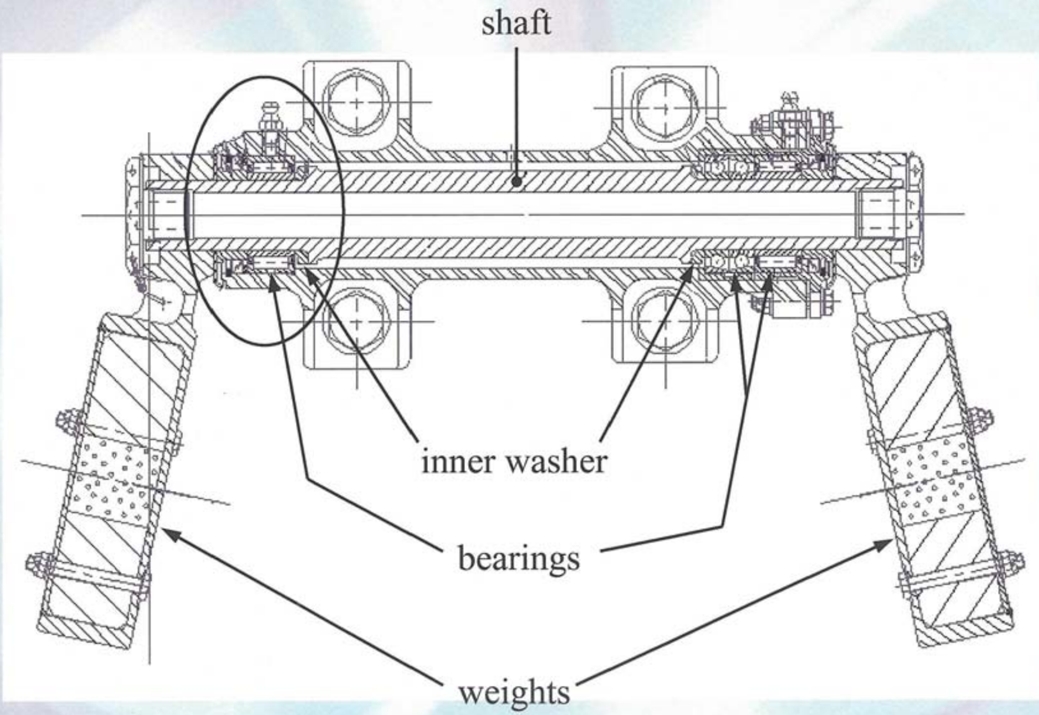
➢ Definition of the blade vibration absorber



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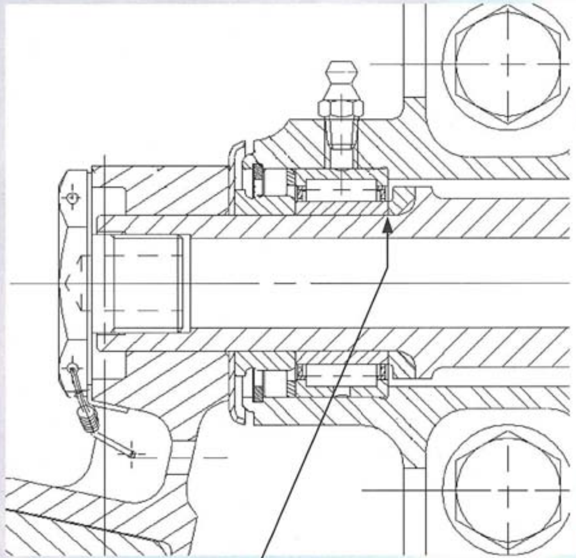
➢ Investigation of the shaft - observations of the crack



Crack initiation on the shaft at the contact with the inner washer (micro-cracks of fretting)

Rotative bending fatigue failure

No default (geometry, material)

Fretting observed on all contact areas

EC Quality Materials Laboratory investigation

↕

AIBN investigation

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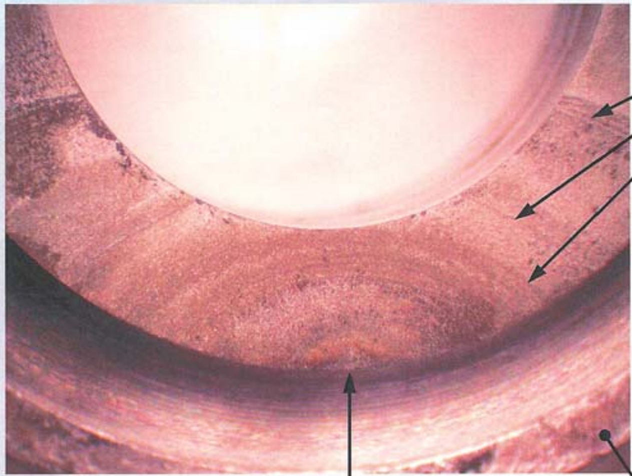
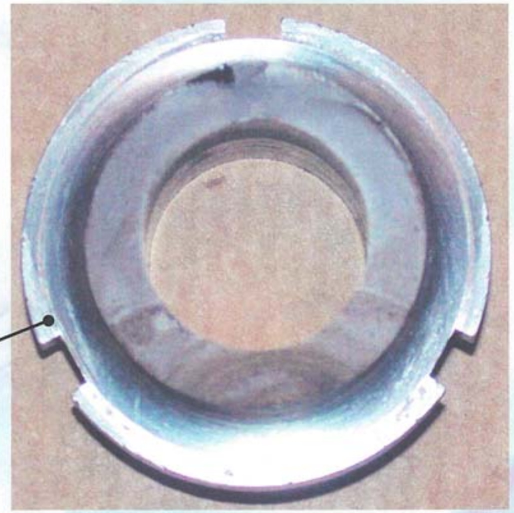
Investigation of the shaft observations of the crack





Quality Materials Laboratory investigation: 50 macro-marks ➡ **Propagation time ≈ 100 hours**

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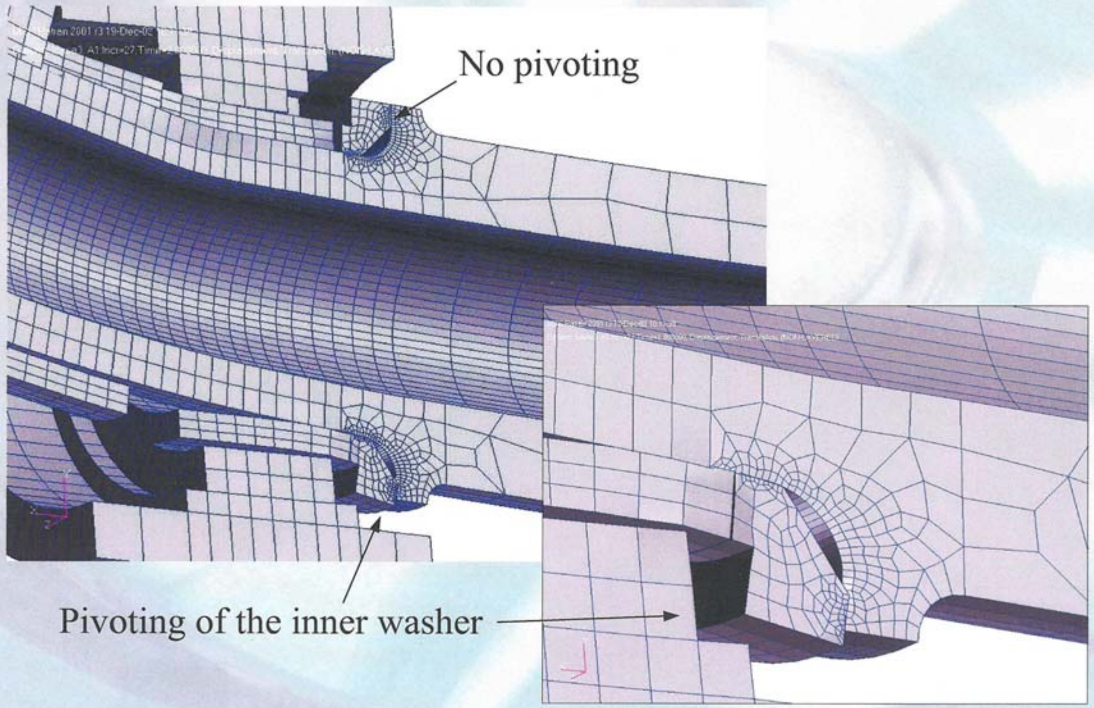
Calculation results

2 - Loss of tightening torque

Model with loss of 80% of the tightening torque



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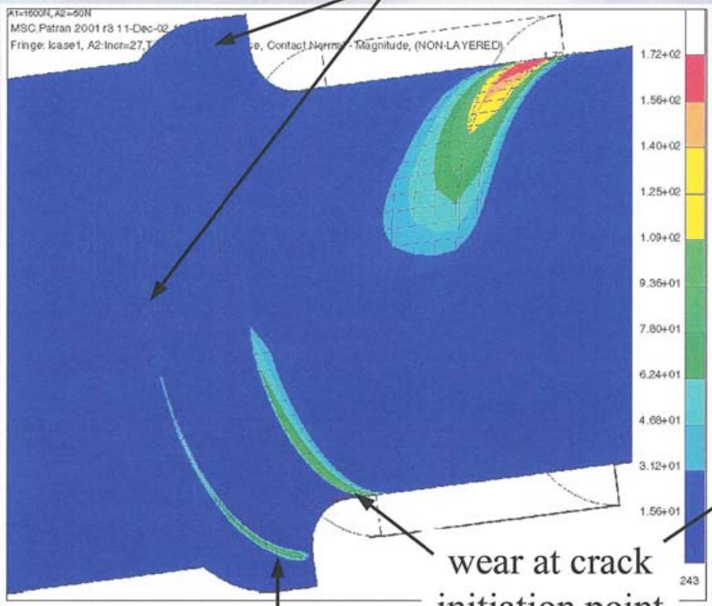
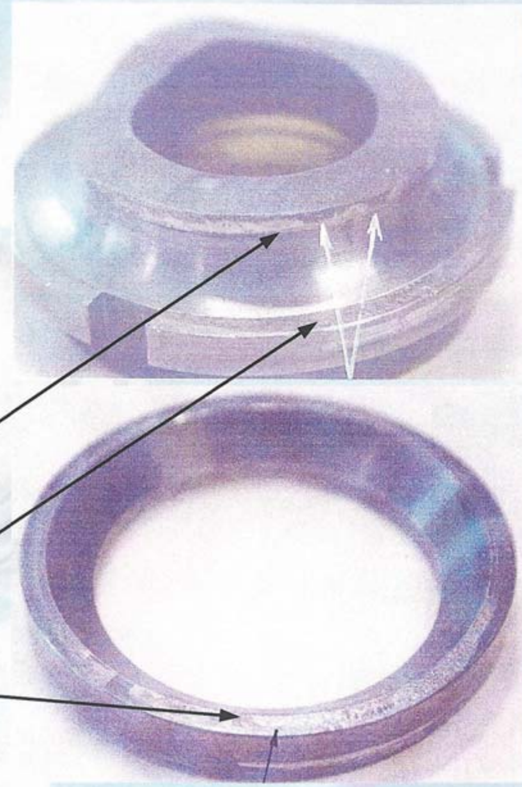
Calculation results

no contact (=> no wear)





wear at crack initiation point

contact pressure area (=> wear)

Results confirmed by observations on the shaft:

wear area on the shaft shoulder at the crack initiation level

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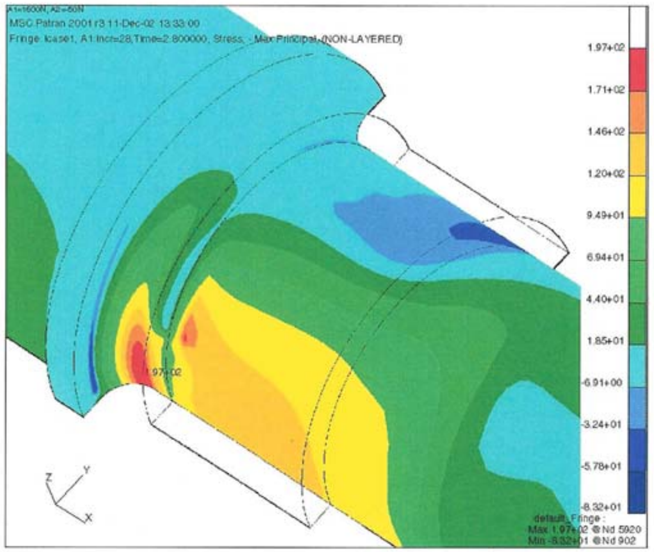
Calculation results



Maximum equivalent stress at the crack initiation point :

σeq. = ± 171 MPa

(tension + torsion at max flight loads)

Material fatigue limit with fretting:

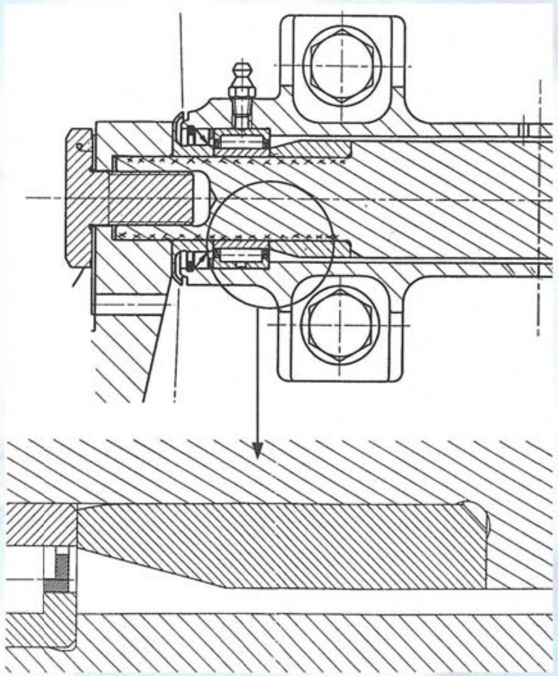
f / k' = ± 150 to 170 MPa

➡ Propagation of possible fatigue fretting micro-cracks

Terminal Actions:

Modification project

- long inner washer (25 mm)
  - ↳ - no fretting wear (better contact pressure distribution without pivoting)
  - - lower strain level under loads
- hard deposit on shaft under bearing and inner washer
  - ↳ fretting prevention
- shrinking of inner washer on shaft
- optimised tightening torque
- bearing reliability improvement



The Finite Element model done shows that even after a complete loss of tightening torque the stress level is low enough to guarantee the safety.

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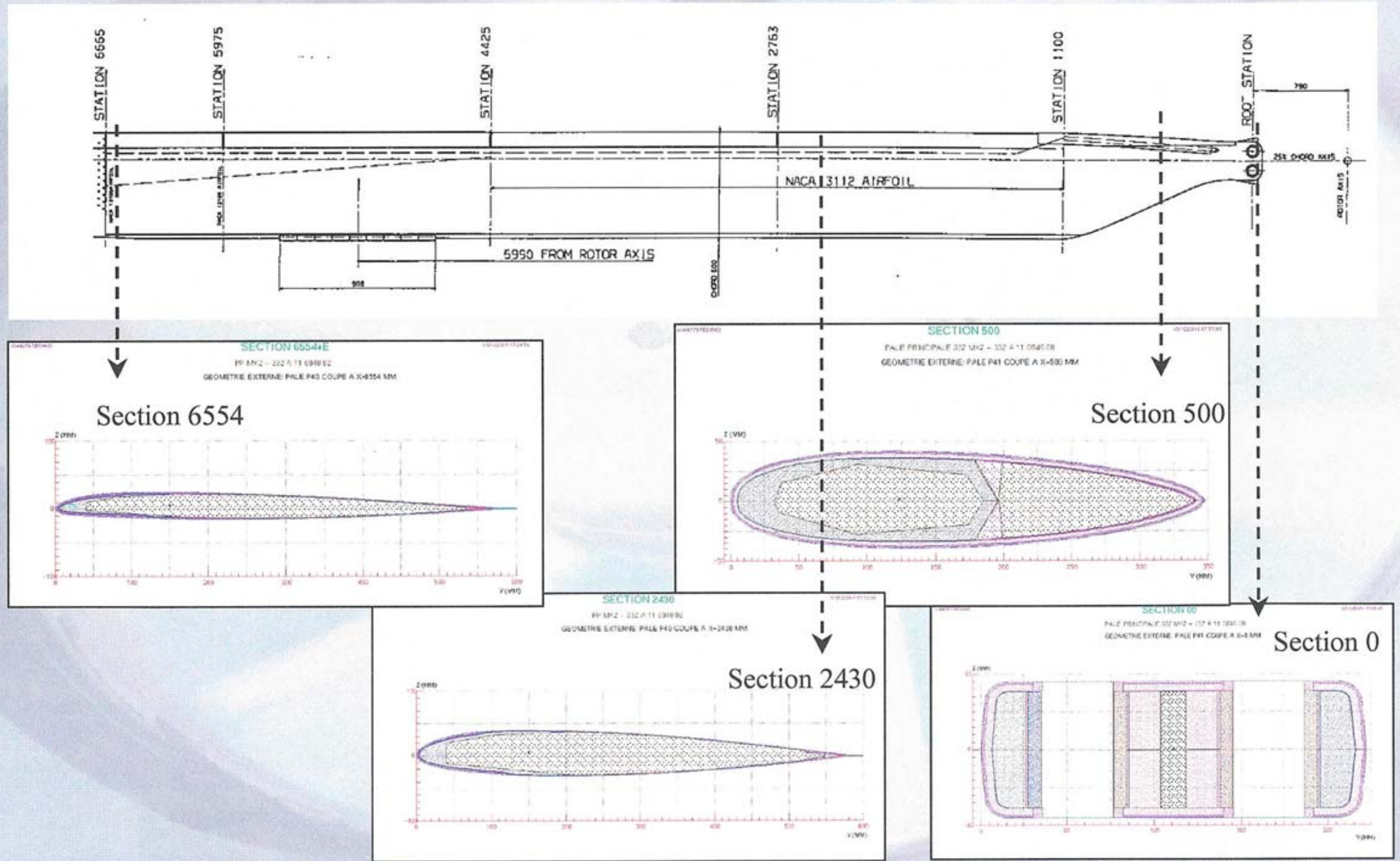
Blade definition

Main rotor blade 332 A 11 0041



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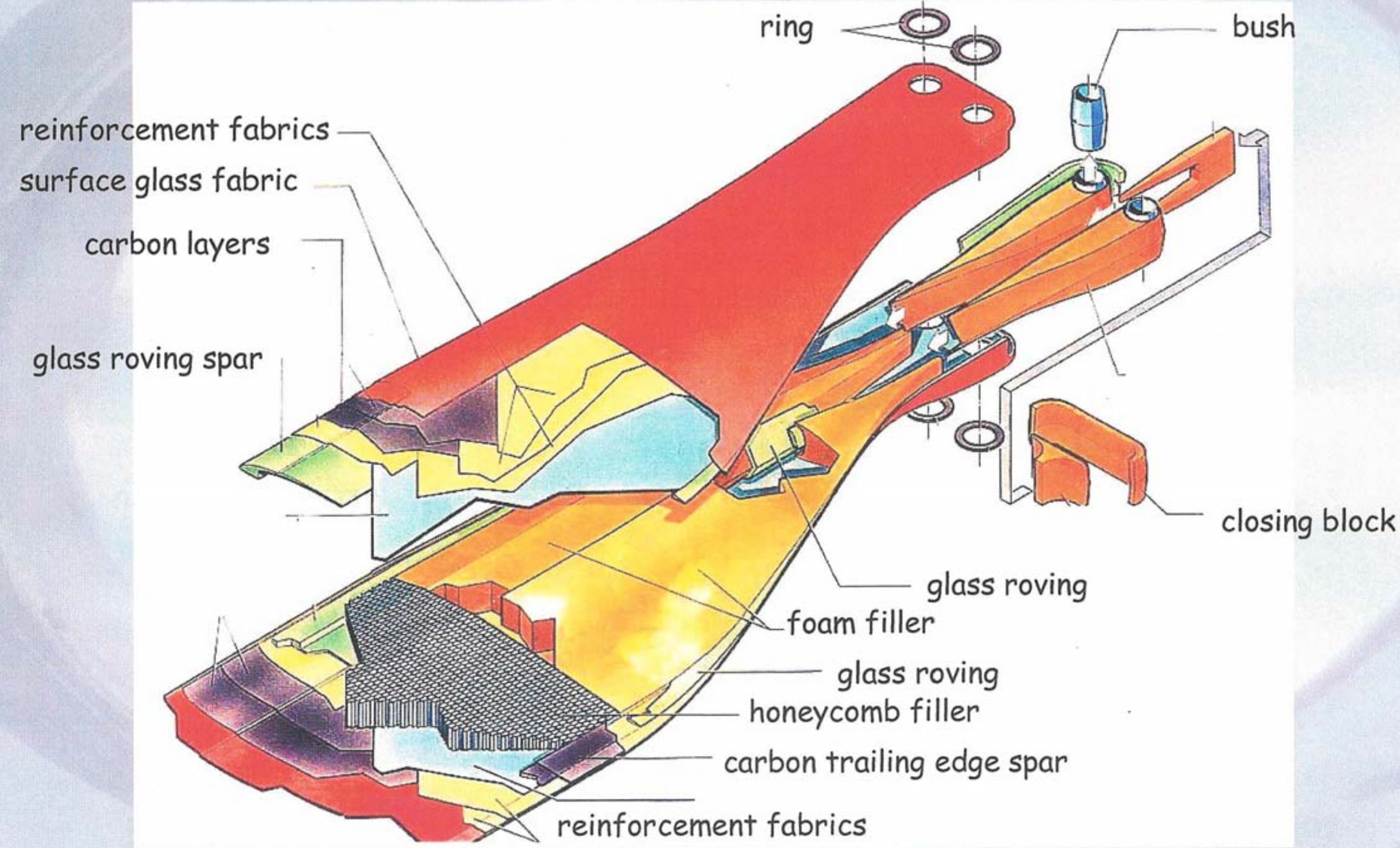
Blade definition

Main rotor blade 332 A 11 0041

Attachment Part



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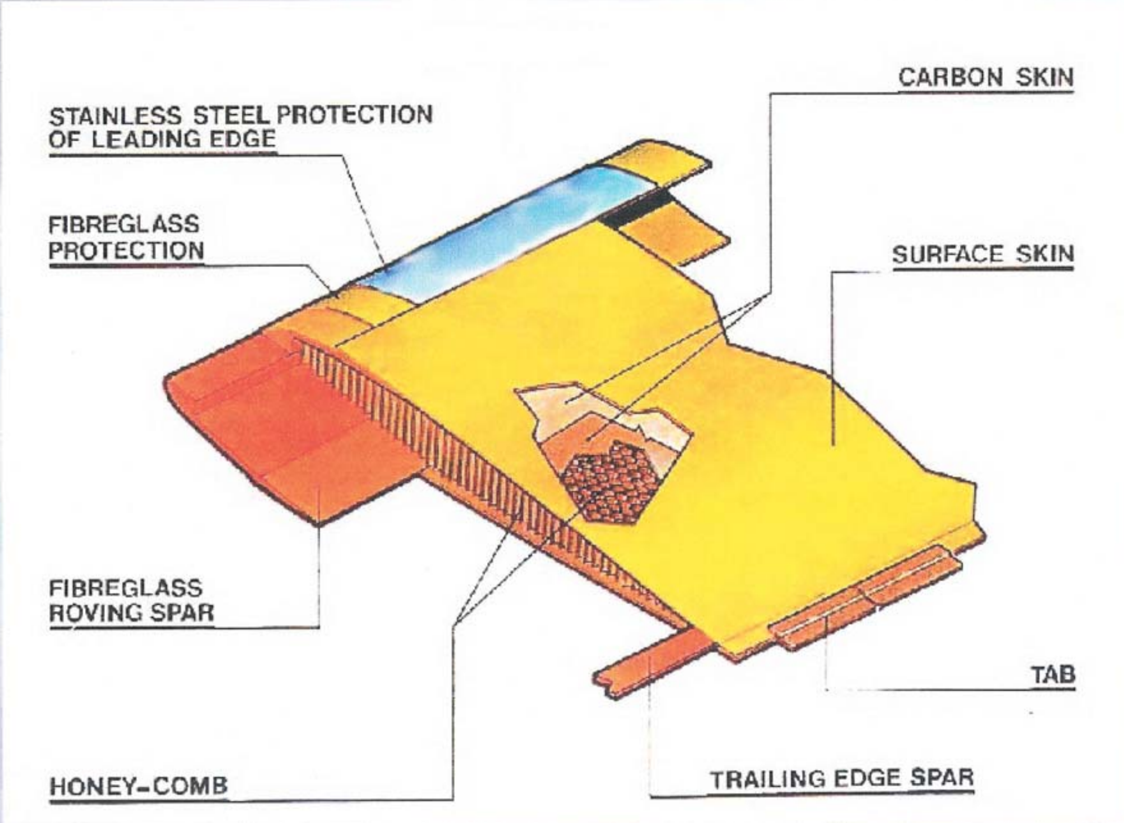
Blade definition

Main rotor blade 332 A 11 0041

Airfoil Section



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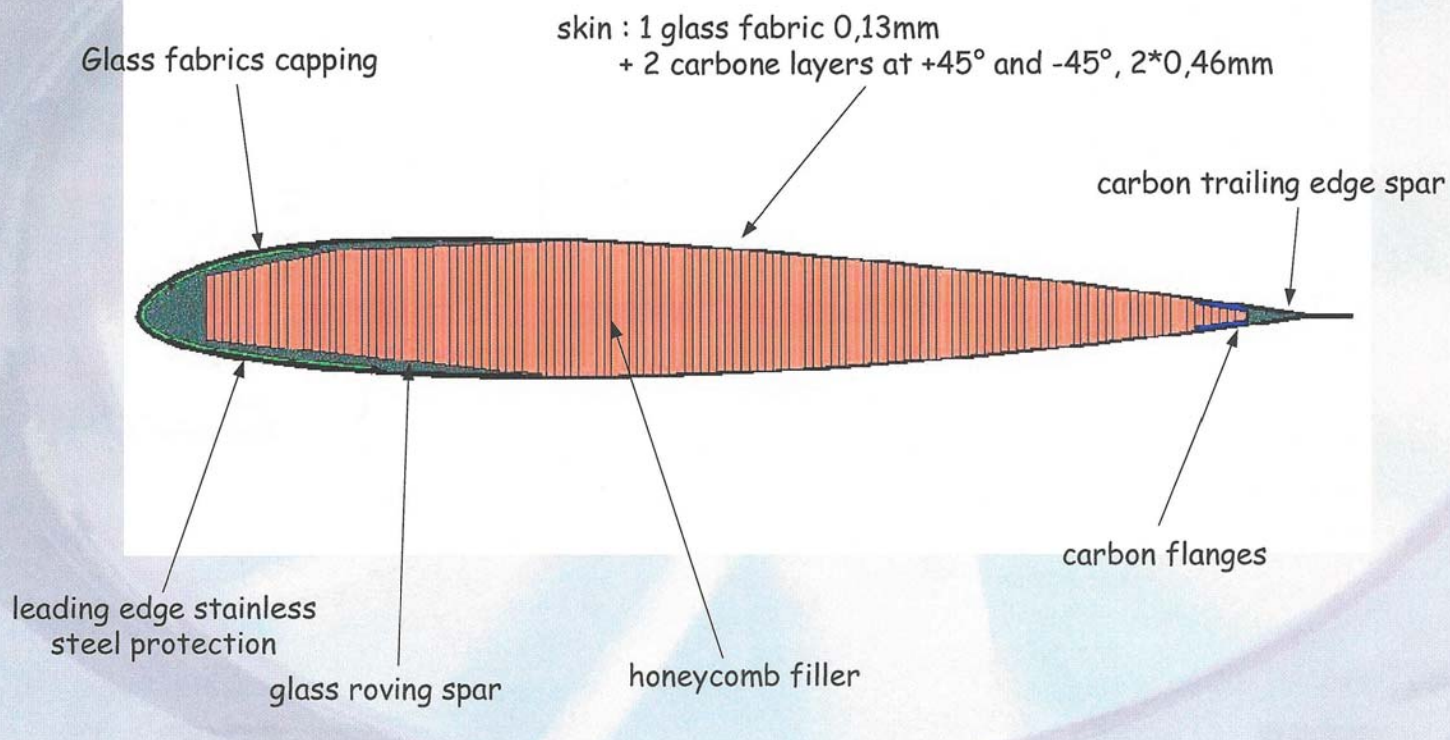
Blade definition

Main rotor blade 332 A 11 0041

Airfoil Section



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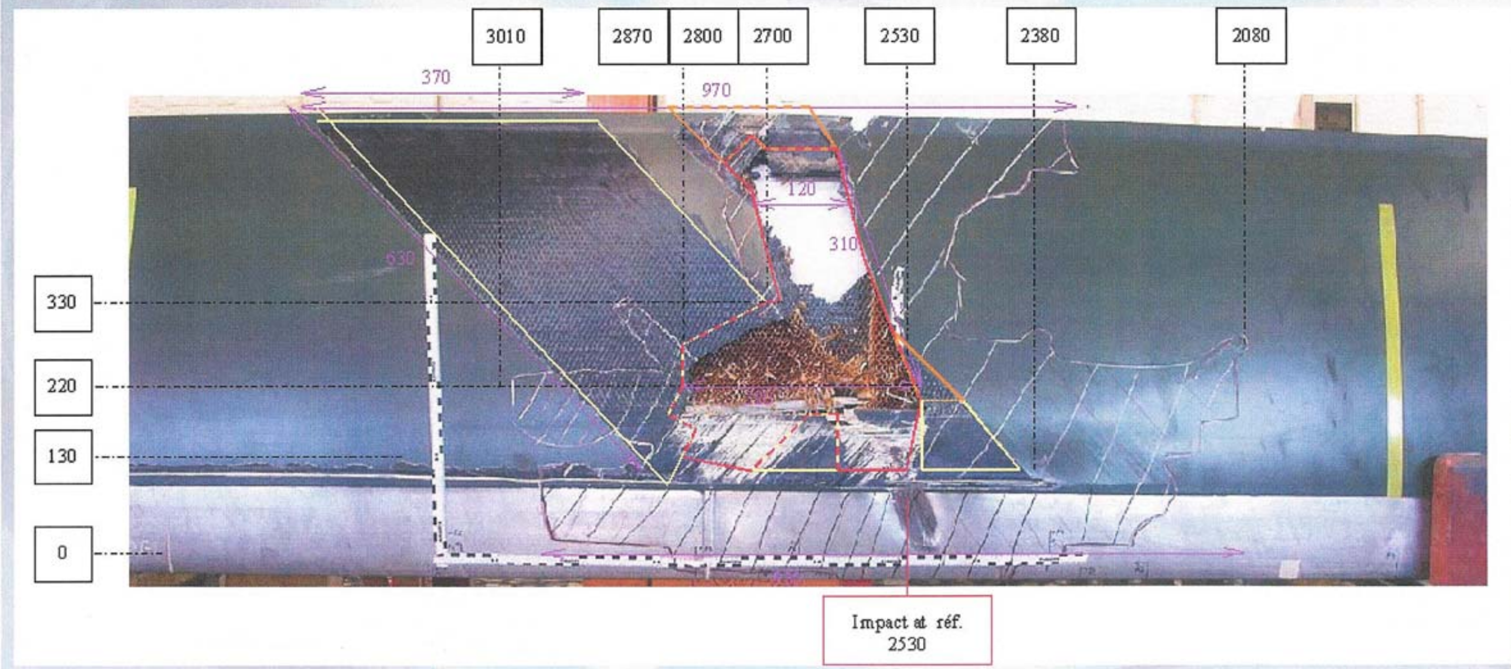
Damaged blade investigation

Investigation of the main rotor blade 332 A 11 0041 n°140

.Non destructive controls

☞ Intrados visual controls and Sound controls :



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Damaged blade investigation

Investigation of the main rotor blade 332 A 11 0041 n°140

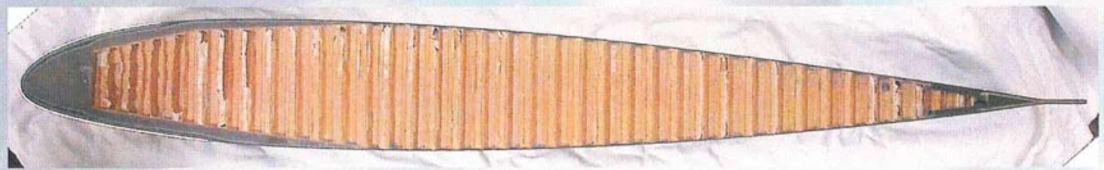
.**Non destructive controls**

☞ **Extrados visual controls and Sound controls :**

Trailing edge failure at ref. 2700

Investigation of the main rotor blade 332 A 11 0041 n°140

.Destructive controls



Ref 1875

Without damages

Ref 2530

Damaged

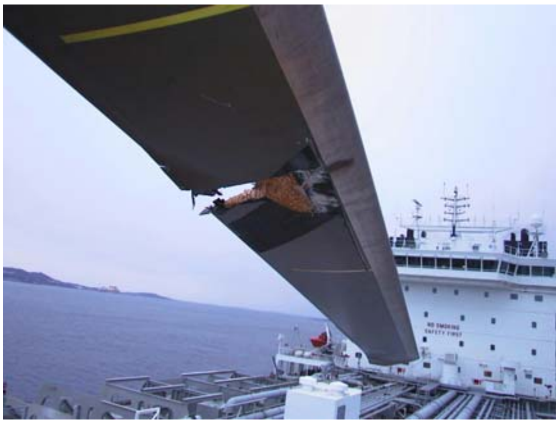
Ref 2700

Damaged

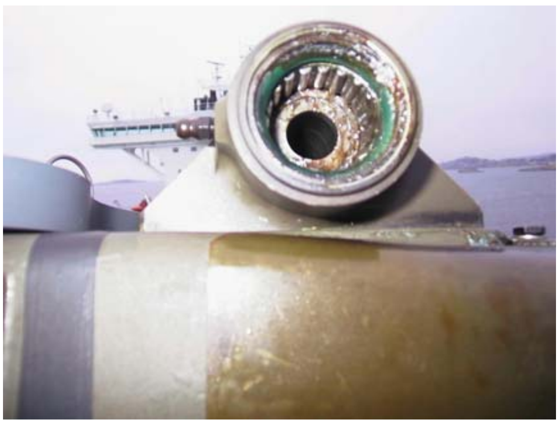
Ref 3525

Without damages

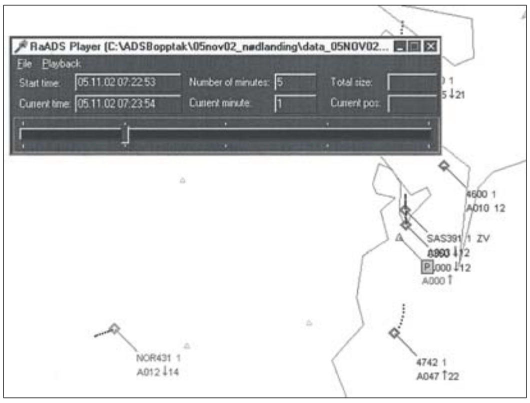
LN-ONI on helideck of M/T Navion Anglia



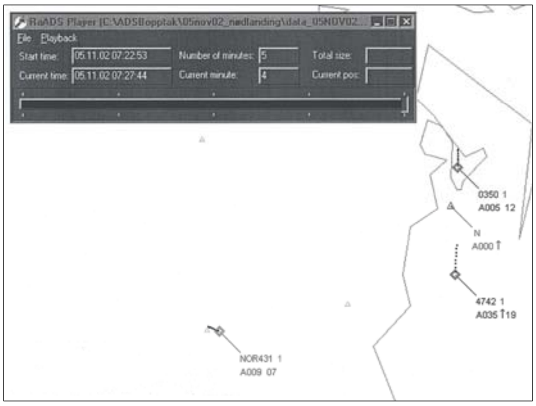
The damaged Blue blade observed from the helicopter



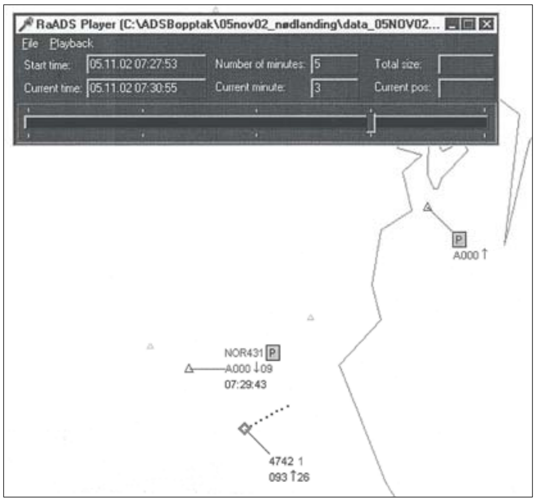
The remaining vibration absorber assy on Blue blade



RaADS plot at time 07:23:54. NOR431R255/17DME ZOL MAYDAY



RaADS plot at time 07:27:44. NOR 431 on course towards ship Navion Anglia



RaADS plot at time 07:30:55. NOR431 landed on helideck Navion Anglia at time 07:29:43