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(AAIB/N)

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REPORT

AIR ACCIDENT INVOLVING EUROCOPTER SUPER PUMA 332L, LN-OBP, IN THE NORTH SEA ON 18 JANUARY 1996, APPROX. 40 NM SOUTH-WEST OF SOLA, NORWAY

SUBMITTED MARCH 1998

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REPORT ON THE AIR ACCIDENT INVOLVING EUROCOPTER SUPER PUMA 332L1, LN-OBP, IN THE NORTH SEA ON 18 JANUARY 1996, APPROX. 40 NM SOUTH-WEST OF SOLA, NORWAY

Aircraft type:	Eurocopter Super Puma AS 332L1
Registration:	LN-OBP
Call sign:	HKS 551
Owner:	Helikopter Service AS, Stavanger Airport Sola, Norway
User:	As above
Crew:	2
Passengers:	16
Accident site:	North Sea, 58° 14' N, 005° 09'E
Time of accident:	18 January 1996, approx. 08.45 hours

All times given in this report are local times (UTC + one hour), if not otherwise stated.

NOTIFICATION

On 18 January 1996, at 09.45 hours, a representative of Helikopter Service AS (HS) telephoned the Aircraft Accident Investigation Board, Norway (AAIB/N) to report that a Super Puma helicopter had made an emergency landing at sea, approx. 30 NM out of Egersund. A short time after this, both the Oslo Police Operations Centre and the Rescue Coordination Centre for southern Norway (HRSS) both reported the same incident. A report also came in that the crew and passengers had been rescued safely and had been flown to Stavanger by two rescue helicopters scrambled from 330 Squadron. The helicopter floated on its emergency flotation gear, and the company was given permission by the AAIB/N to start salvage work immediately. The AAIB/N was on site at HS premises at 08.00 the following day and interviewed the 2 crew members. It appeared that the helicopter had capsized during the course of the night due to a deterioration in weather conditions and on 19 January, at approx. 17.00 hours, it sank in a water depth of approx. 285 metres. At this time there were strong winds in the area. The search for the helicopter commenced once the weather improved a few days later. On 26 January, at 18.30 hours, the AAIB/N received a report that the helicopter had been found by a search vessel. The helicopter and one main rotor blade were salvaged on 27 January and were brought to the HS hangar on 28 January. The AAIB/N began its investigations, with 3 inspectors, at the HS premises in Stavanger on 29 January 1996, at 09.00 hours. In accordance with international agreements, the French accident investigation bureau, Bureau Enquêtes-Accidents (BEA), was notified. BEA appointed an accredited representative and sent to Norway a staff of two and a technical adviser from the manufacturer (Eurocopter) to take part in the introductory phase of the investigations. Later, BEA was a participant, periodically, in the technical part of the investigations.

SUMMARY

A Super Puma helicopter from Helikopter Service AS, on an assignment for BP Norge, took off from Sola on 18 January 1996 at 08.16 hours, with 16 passengers and a crew of 2, for a scheduled flight to oil installations in the North Sea. The flight was undertaken in clouds. Weather conditions were otherwise favourable, with relatively little wind and precipitation. After flying for approx. 26 minutes, strong vibrations suddenly occurred in the helicopter. The vibrations were of such magnitude that the crew chose to carry out an emergency landing at sea. Only during the descent were the crew members able to relate the vibrations to the main rotor - they decreased with a low rotor loading and increased as the load increased. The helicopter broke out of the cloud at approx. 600 ft above sea level and was set down on the water at approx. 08.45 hours. The wind was approx. 25-30 kt, with wave height of 3-4 m.

After landing, the helicopter floated primarily by means of the flotation gear attached to the sides of the fuselage. Both life rafts (one in each sponson) were released electrically from the cockpit and all passengers and the Co-pilot boarded the raft on the port side while the Pilot-in-Command attempted to free the raft on the starboard side, which had blown up onto the roof of the helicopter. There was some drama when the raft on the port side drifted backwards and went under the tail boom. The tail boom was pitching violently in the sea and was striking the raft. This led to one of the raft's flotation chambers being punctured. Several people fell overboard, and some chose to swim back to the helicopter. Eventually, everyone managed to return to the helicopter.

The Pilot-in-Command was given assistance in retrieving the starboard raft, and he and 3 of the passengers managed to board it. Because all lines had been cut to free the raft from the roof, it drifted away from the helicopter. The rest of the passengers and the Co-pilot remained in the helicopter, where the water was at a level of around 30 cm above the floor. Several people became seasick as a result of the motion and the strong smell of fuel which was being forced out of the tanks. After approx. one hour, two helicopters from the rescue service arrived at the scene and winched up everyone from the helicopter and from the starboard raft. Despite immediate measures being taken by the company to salvage the helicopter, this was unsuccessful because of the considerable deterioration in the weather during the

hours which followed. The helicopter capsized during the course of the evening and sank the next day to a depth of approx. 285 m. During salvage preparations on the surface, photographs of the helicopter were taken which clearly showed a fault on the outermost part of the leading edge strip of one main rotor blade. The helicopter and the relevant rotor blade were salvaged from the seabed approx. one week after they sank.

As part of its investigations, the AAIB/N has undertaken comprehensive examinations of the affected main rotor blade, with the assistance of Det Norske Veritas (DNV). By means of these investigations, it has been established that a fold, approx. 7.5 cm in size, from the outermost, upper part of the titanium leading edge strip of the rotor blade had become raised up in the air flow and caused the vibrations. The reason for this was that the titanium strip was greatly eroded on its leading edge, while the leading edge was also loose in relation to the base layer below. Together, these caused a longitudinal crack in the leading edge of the strip. In addition, a modification had been carried out in that area, which weakened the strip. Aerodynamic forces were therefore able to have an effect on the titanium sections and lift a fold on the strip approx. 22° from the horizontal plane. The AAIB/N has studied the production process and the maintenance routines for this type of blade. On the basis of these investigations, the AAIB/N believes that there is particular potential for improvement both in the fields of design and maintenance. As regards production, the AAIB/N particularly wants to stress the importance of maintaining an ongoing quality process with the highest level of control.

The AAIB/N has also undertaken comprehensive evaluations of the personnel-related safety conditions which apply during the helicopter transportation of people to offshore oil installations in the Norwegian sector of the Continental Shelf. The AAIB/N is of the opinion that there is also room for improvement in this area in terms of equent and procedures.

1 FACTUAL INFORMATION

1.1 History of the flight

1.1.1 Helikopter Service AS (HS) carries out air transportation services for BP Norge (BPN) on a contract basis, from Stavanger's Sola airport to oil installations in the North Sea. Various models of the Eurocopter Super Puma 332 helicopter are used for this service.

1.1.2 On 18 January 1996, a flight carrying 16 passengers was to be made for BPN on an IFR flight plan, to the Gyda and Ula platforms. All passengers were wearing insulated orange survival suits of different types, but all types were approved by the Norwegian Directorate of Shipping and Navigation. Wearing the suits during the journey is a mandatory requirement of the oil operator. These are the same suits which are mandatory on board the oil installations. The 2 crew members were wearing the airline's dark blue non-insulated survival suits. The helicopter, call sign HKS 551, took off from Sola at 08.16 hours, with an estimated time of arrival of 09.45 hours at the Gyda platform. The Co-pilot was the Flying Pilot (FP). After departure, the crew followed the usual outgoing flight procedures, established a cruising altitude of 2,000 ft, passed the DEPEK reporting point and then established on the ALFA track (216°) (see Appendix 1). The cruising phase took place in clouds. There was no icing during the flight.

1.1.3 At 08:42:33 hours, when the helicopter was located approx. 25 NM from land, heavy vibrations suddenly occurred in the aircraft. It was difficult for the crew immediately to be able to identify the vibration. Nor were they able to register any fault when reading the instruments. Because the level of vibrations was so great, the crew did not consider it justifiable to continue the flight and they quickly decided to attempt a controlled emergency landing in the sea. The Pilot-in-Command issued a distress signal (MAYDAY) at 08:42:46 hours, which was responded to by the Stavanger Air Traffic Control Centre (ATCC). The passengers were then warned to prepare themselves for landing on the water. No information about using the life jackets carried on board was included in these preparations. A controlled descent under engine power was then commenced. The vibrations reduced somewhat when the loading on the main rotor was reduced during the descent.

1.1.4 At an altitude of approx. 600 ft, the helicopter broke through the cloud base. At approx. 400 ft, the helicopter's emergency flotation gear (4 fuselage-mounted inflatable flotation elements) was activated. After a short assessment of the situation, and while the helicopter was hovering, the crew decided that they would carry out the landing and the helicopter was set down in the water in a controlled manner at approx. 08.45 hours. At this time, the wind was from 150° and was approx. 25-30 kt. The wave height was between 3 and 4 metres. The vibrations in the helicopter increased when the loading on the main rotor was increased during hovering and landing.

1.1.5 Immediately after the ditching, the Pilot-in-Command took over the controls and switched off the engines. The two life rafts, which were packed into the starboard and port side sponsons respectively were released electrically from the cockpit. The sea anchor was also released. The externally-mounted emergency locator transmitter (ELT, also called CPI) was released from the helicopter at the same time (thereby also being activated). At the same time, the Co-pilot left his seat to attend to the passengers. En-route from the cockpit, he put on his life jacket and, from the bulkhead separating the cockpit and the cabin, he took a first aid box and a portable emergency transmitter (see Figure 8). He instructed the passengers in what action to take. There was no evidence of unease. The port cabin door (the leeward side) was opened by the Co-pilot. Outside he could see the port life raft which was already inflated. He could also make out the starboard raft which had blown up onto the roof of the helicopter. He took hold of the port raft and pulled it towards the open door. All of the passengers and the Co-pilot then quickly boarded the raft. This immediately drifted along the helicopter and in under the tail boom. One chamber of the raft was punctured after a short while owing to the tail-boom structure hitting the raft with force. There was a moment of drama when the raft was punctured and some of the passengers fell into the water in an attempt to avoid being hit by the tail-boom which was pitching wildly in the sea. Finally, all 17 on board the raft managed to make their way back into the helicopter again, some by swimming back to the port side main door.

1.1.6 In the meantime, the Pilot-in-Command was trying to bring down the starboard raft which had been blown up onto the roof of the helicopter. Eventually, he was helped by one of the passengers who returned to the helicopter from the port raft, and by cutting the lines/ropes which had become entangled, the raft was finally put in the water. 3 people managed to board this, in addition to the Pilot-in-Command, but the raft then drifted away because it was not possible manually to hold it close to the helicopter.

1.1.7 Because of this, there were 13 passengers and the Co-pilot back on board the helicopter. All of these were rescued approx. 1 hour after the emergency landing, when the first helicopter from the rescue service arrived on the scene. The 4 people in the starboard raft, who were now located approx. 200 m from the helicopter, were rescued by the second helicopter which arrived on the scene a few minutes after the first.

1.1.8 A helicopter from Norsk Helikopter AS arrived a short time after the emergency landing and circled close to the stricken helicopter.

1.2 Injuries to persons

INJURIES	CREW	PASSENGERS	OTHERS
FATAL			
SERIOUS			
MINOR/NONE	2	16	

1.3 Damage to aircraft

1.3.1 The helicopter was not damaged directly during the emergency landing. Because the water level was above the cabin floor, there may have been large-scale salt water damage if the helicopter had been salvaged from its surface position.

1.3.2 The helicopter sank the day after the emergency landing in a water depth of approx. 285 metres, but all significant parts were salvaged a few days later. The helicopter sustained so much damage in connection with sinking to the seabed that it must be regarded as a total write-off. The insurance value was NOK 75 million.

1.4 Other damage

None.

1.5 Personnel information

1.5.1 The Pilot-in-Command

1.5.1.1 The Pilot-in-Command, a man aged 34, holds a commercial pilot's licence for helicopters (ATPL-H). The licence was issued on 17 August 1992 and was valid until 30 September 1996. The last medical examination for the commercial pilot's licence was carried out on 11 January 1996. The Pilot-in-Command's licence is valid for the following types of helicopter: AS 332, Bell 204, Bell 205 and Hughes 300.

1.5.1.2 The Pilot-in-Command received his training in the Norwegian Air Force. After training, his service included 8 years on Sea Kings in 330 squadron.

1.5.1.3 The Pilot-in-Command was employed by Braathens Helikopter AS in 1990. This company later became part of Helikopter Service AS.

1.5.1.4 The Pilot-in-Command's total number of flying hours as at 18 January 1996 was 5,344 hours. As at the same date, his number of flying hours on the type of helicopter in question was 2,873. He undertook his last session of periodic flight training on 16 November 1995. The day before the emergency landing, he had undertaken mandatory emergency training at NUTEC in Bergen.

1.5.1.5 The Pilot-in-Command has stated that, at the start of duty on 18 January 1996, he was well rested after a normal night's sleep.

FLYING EXPERIENCE	TOTAL	ON TYPE
LAST 24 HOURS	0:30	0:30
LAST 3 DAYS	5:00	5:00
LAST 30 DAYS	25:00	25:00
LAST 90 DAYS	117:00	102:00

1.5.2 The Co-pilot

1.5.2.1 The Co-pilot, a man aged 32, holds a commercial pilot's licence for helicopters (CPL-H) and an instrument licence. In addition, he holds a Private Pilot's Licence

(PPL-A) for single-engined aircraft. The licences were issued on 23 July 1987 and were valid until 30 September 1996. The last medical examination for the commercial pilot's licence was carried out on 13 November 1995. The Co-pilot's licence is valid for the following types of helicopter: Hughes 300, Bell 204/205/212/412 and AS 332L/L1.

1.5.2.2 The Co-pilot received his training in the Norwegian Air Force. After training, he served in 337 and 339 squadrons.

1.5.2.3 The Co-pilot was employed by Braathens Helikopter AS in 1992. This company later became part of Helikopter Service AS.

1.5.2.4 The Co-pilot's total number of flying hours as at 18 January 1996 was 4,934 hours. The number of flying hours in the type of helicopter in question was 1,823 hours as at the same date. He undertook his last session of periodic flight training on 17 October 1995.

1.5.2.5 The Co-pilot has stated that at the start of duty on 18 January 1996, he was fully rested after a normal night's sleep.

FLYING EXPERIENCE	TOTAL	ON TYPE
LAST 24 HOURS	0:30	0:30
LAST 3 DAYS	0:30	0:30
LAST 30 DAYS	20:00	20:00
LAST 90 DAYS	83:35	83:35

1.6 Aircraft information

1.6.1 Helicopter data:

Manufacturer:	Eurocopter France
Type/model:	Super Puma AS 332L1
Year of construction:	1990
Serial number:	2308
Total hours of operation:	8,190:27 hours

1.6.1.1 Departure from Sola was with maximum takeoff weight, 8,600 kg. The centre of gravity was within the permitted limits.

1.6.1.2 On departure, there were 1,404 kg of JET A-1 fuel on board.

1.6.2 Description of main rotor blade design (blade containing de-icer element)

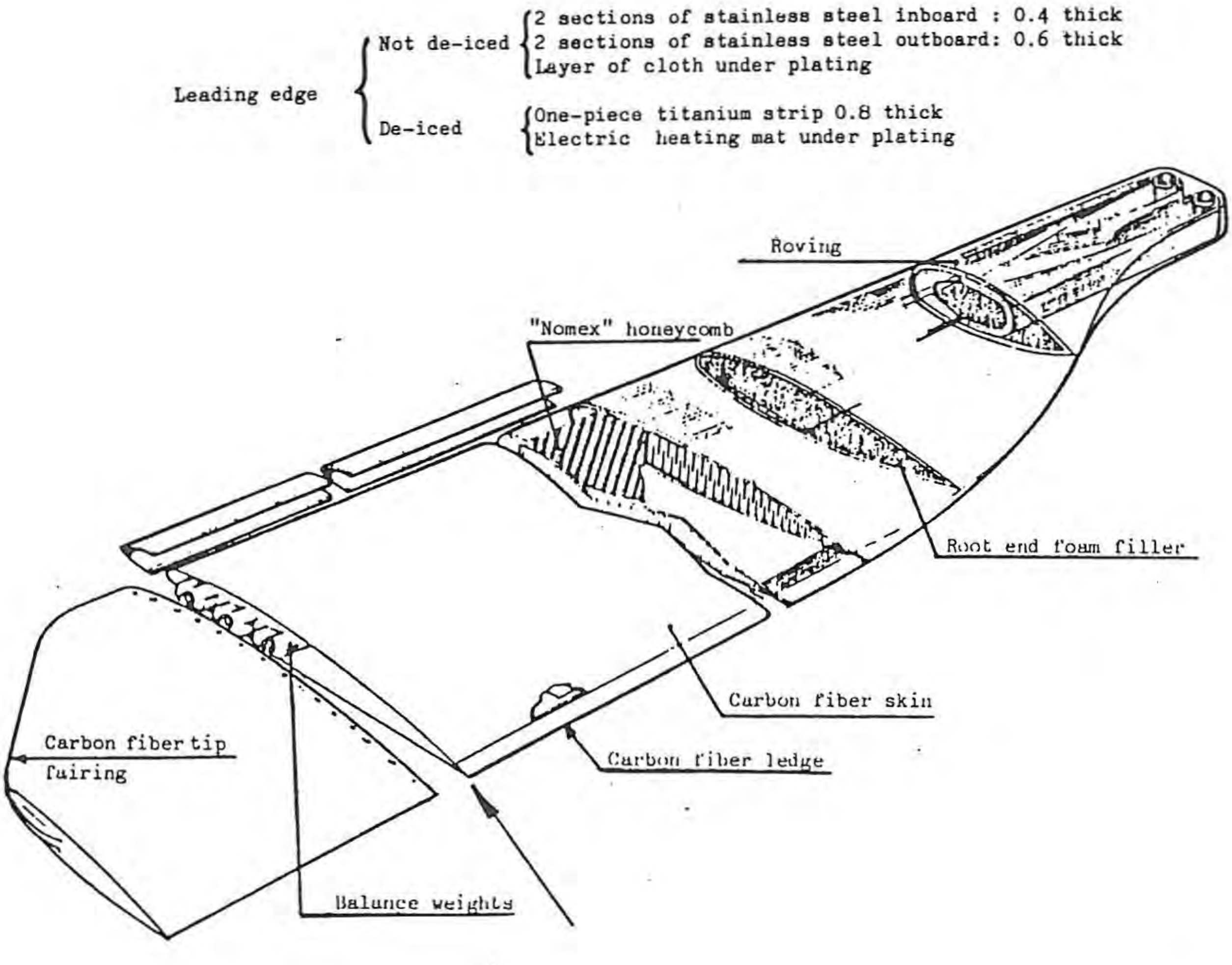
1.6.2.1 The main rotor blade is approx. 6.65 m long, excluding the blade tip. A simplified illustration of the design is given in Figure 1. The core of the blade consists of honeycomb, and this is enclosed in a skin of carbon fibre. Most of the leading edge of the blade is covered by a leading edge strip, also called an erosion shield, made of 0.8 mm Titanium T-40 (a French designation equivalent to ASTM Ti Grade 2 - Unalloyed Titanium). Located under this strip is a de-icer element (an electric heating element coated in neoprene). Figure 2 shows a cross-section of the blade. The different layers of the leading edge is shown in the sketch in Figure 3 and in the picture in Figure 4. The outer end of the blade is sheathed in a tip cap with a leading edge of steel. For this investigation, the line between the blade and the tip cap of the blade has been defined as a zero line for longitudinal measurements carried out on the blade. This zero line is marked with an arrow in Figure 1.

1.6.2.2 As a starting point, the structure of the main rotor blade of the Super Puma AS 332 is identical for blades both with and without de-icing elements (De-ice and Standard, respectively). The difference lies in the fact that, with no de-icer, the electrical elements in the blades have been replaced with additional layers of fibreglass sheeting. To protect these from erosion, a leading edge strip of stainless steel, divided into four segments, has been used.

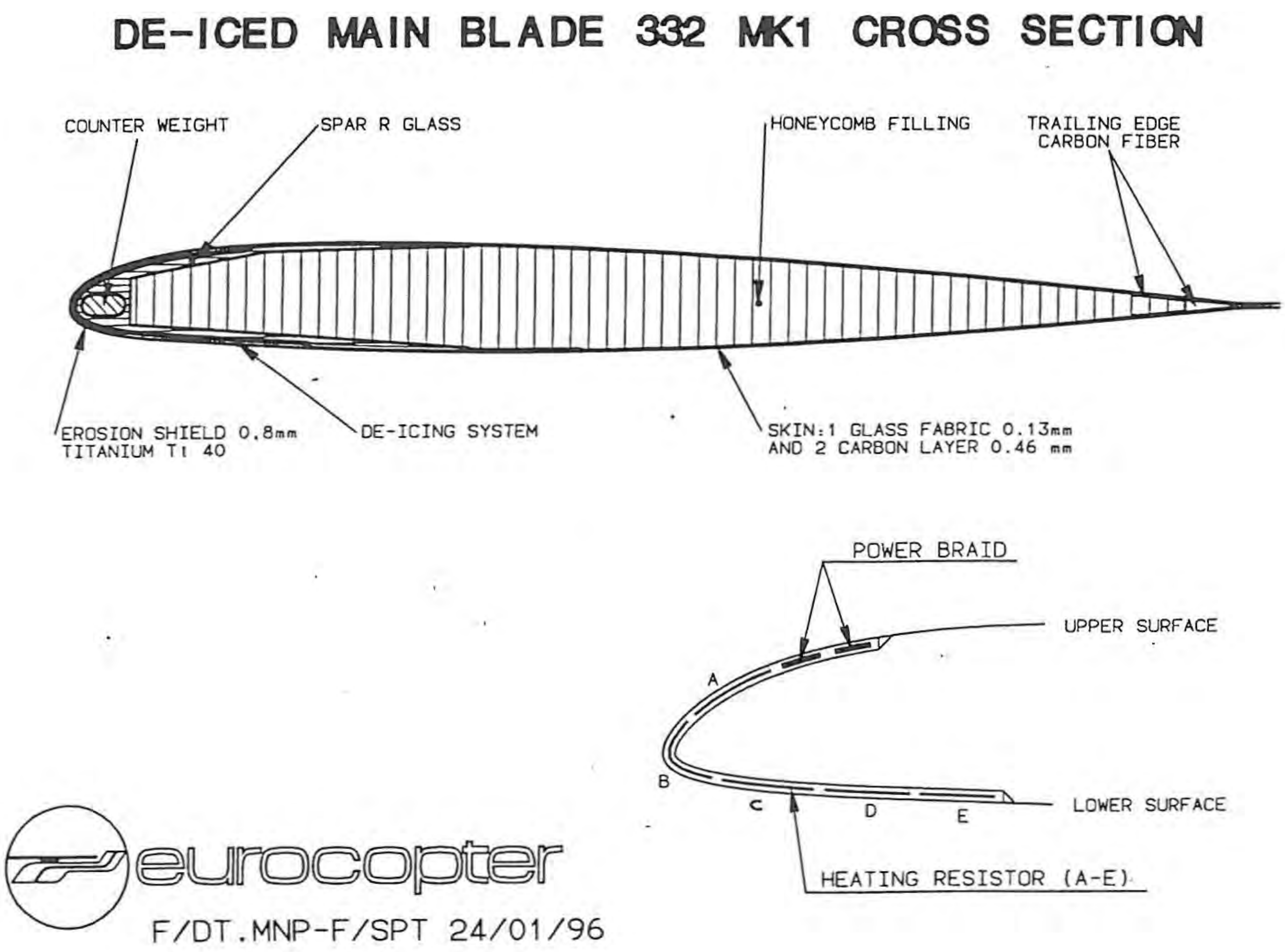
1.6.2.3 On request, the factory supplied the information that it chose to use unalloyed titanium for the leading edge strip on blades with de-icer elements, because it was the most appropriate material which was commercially available during the development of this type of blade, and which could be moulded, practically, in one piece along the entire length of the blade. In this way, the de-icer element is less exposed to damage which might otherwise have arisen as a consequence of the movement in the joints between the segments. This also provides the optimum heat transfer performance in icing conditions.

1.6.2.4 The type of rotor blade in question has been given an operational life of 20,000 hours by the manufacturer. According to the information supplied by Eurocopter, the leading edge strip is only fitted to protect the underlying components and the actual rotor blade. The strip has no structural significance and, as a result, can be eroded completely until a hole appears. The strip has no limited operational life since the environment in which the blade operates will be the determining factor for the operating life of the strip. Representatives from Eurocopter have also stated that only a small part of the leading edge strip needed to be attached by vulcanisation to the de-icer element in order to hold the strip in position during operation. The far

FIGUR 1



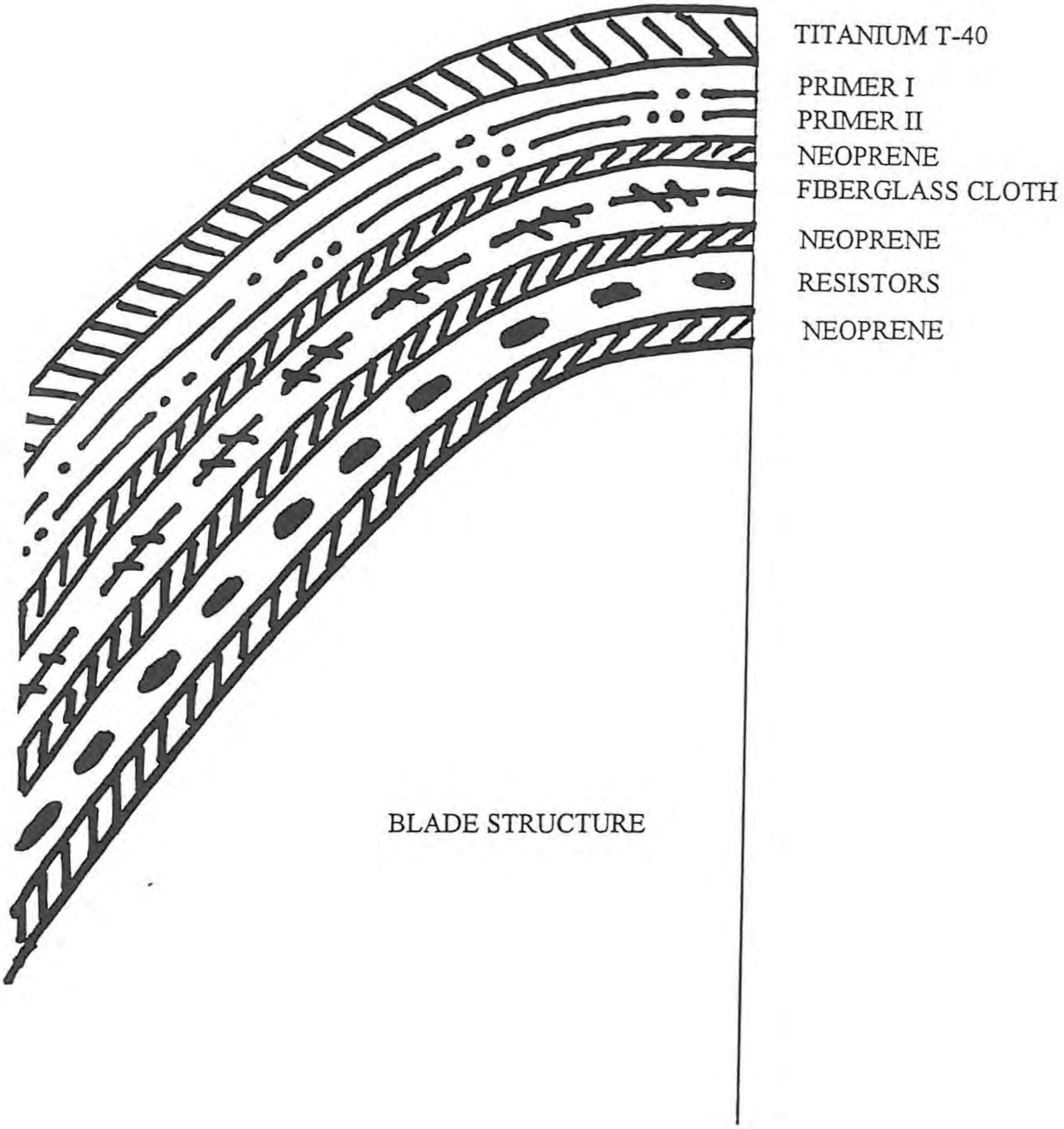
Sketch illustrating the construction principle for the Super Puma MRB. The failed MRB in question is a leading edge de-iced version.

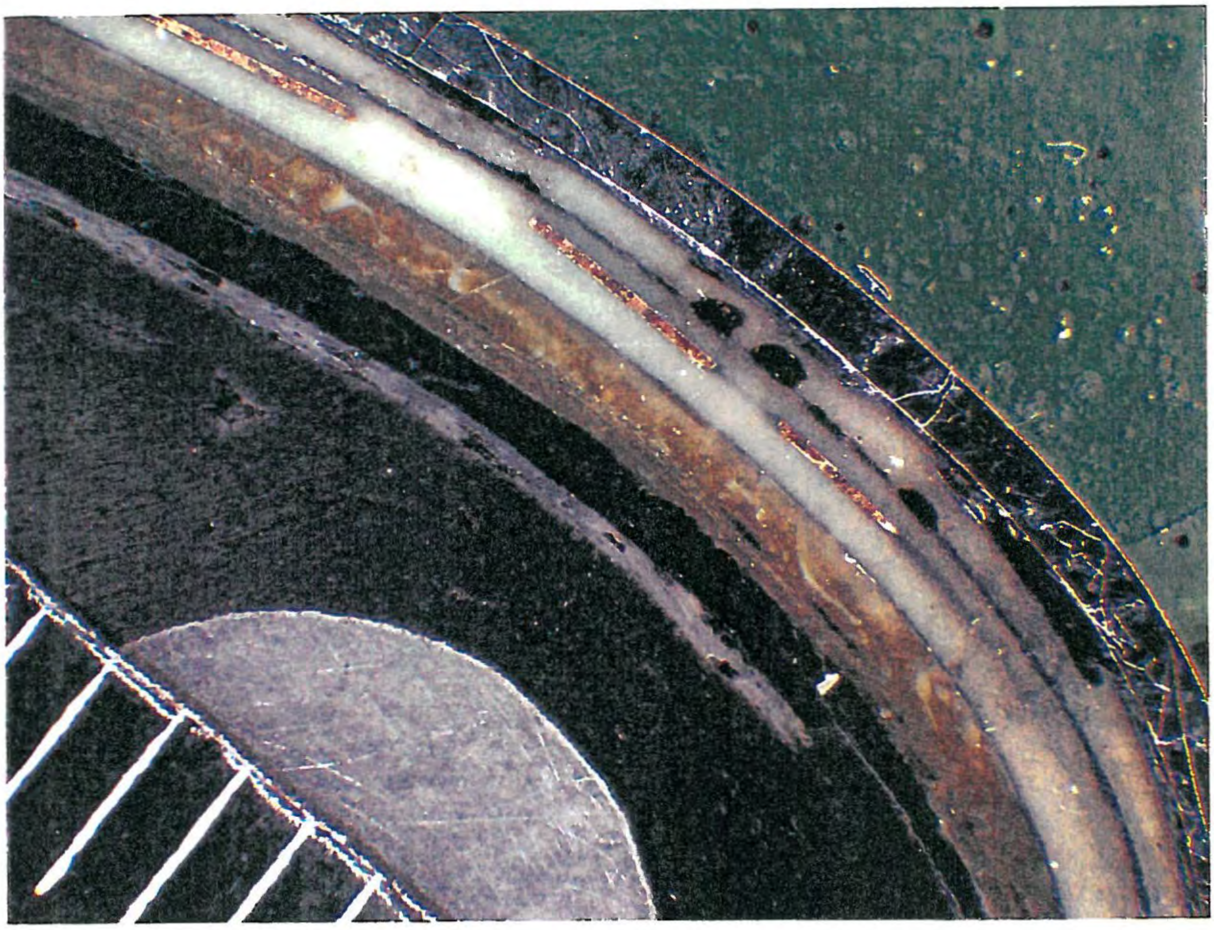


A sketched cross-section view of the MRB for a Super Puma helicopter (de-iced blade version).

FIGUR 3

SCHEMATIC ILLUSTRATION OF LAYERS IN LEADING EDGE





Metallographic close-up photo illustrating the composition/structure of the leading edge section of the main rotor blade.

stricter requirements for maximum areas for delamination set out in the maintenance requirements (see appendix 2), were set to ensure good heat transfer from the de-icer element to the surface of the leading edge strip.

1.6.2.5 On the basis of in service experience, when faults had occurred in the power supply to the de-icer elements, the document Eurocopter Service Bulletin AS 332 No. 01.42, dated 17 January 1995, was issued. This applied a mandatory modification to all main rotor blades with P/N 332A11-0030-03. This work was to be carried out in accordance with 'Eurocopter Technical Instruction No. 230: Redundancing of De-icer Braid Return'. The work consisted of cutting out a piece of the leading edge strip adjacent to the tip cap and making a modification to the underlying power supply to the de-icer element. The modification led to the removal of a mounting lug which went under the blade's tip cap and which was held in place by a mounting screw. After the underlying modification was carried out, the opening was filled in with composite materials (see Figure 5). This modification led to the part number of the rotor blade being changed to 332A11-0030-09. Eurocopter has informed the AAIB/N that this modification did not lead to any new strength calculations for the leading edge strip. The reason for this is that the designer had established that the remaining mechanical links between the titanium strip and the de-icer element were homogeneous and sufficient, and that it was therefore necessary to make new calculations.

1.6.3 The history of blade P/N 332A11-0030-09, S/N 617

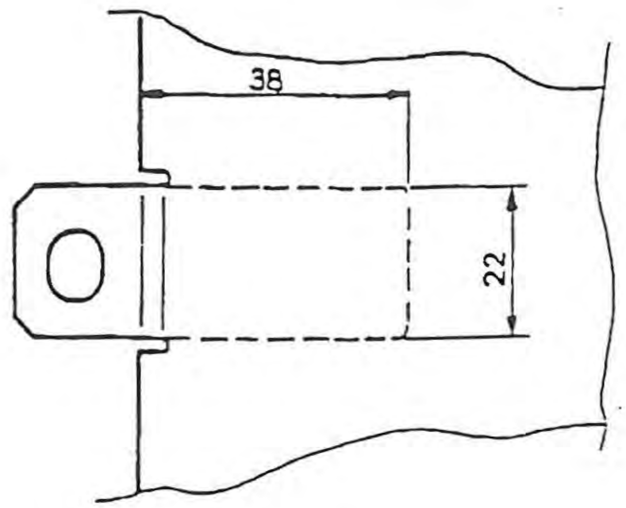
1.6.3.1 The log card for the main rotor blade recorded it as being new on 22 June 1983. At that time, it had P/N 332A11-0030-02. The rotor blade was installed in a helicopter for the first time on 13 May 1985. At one time, the rotor blade changed P/N to 332A11-0030-03. The blade has thereafter been subject to use and maintenance for a fairly long period up to 1991.

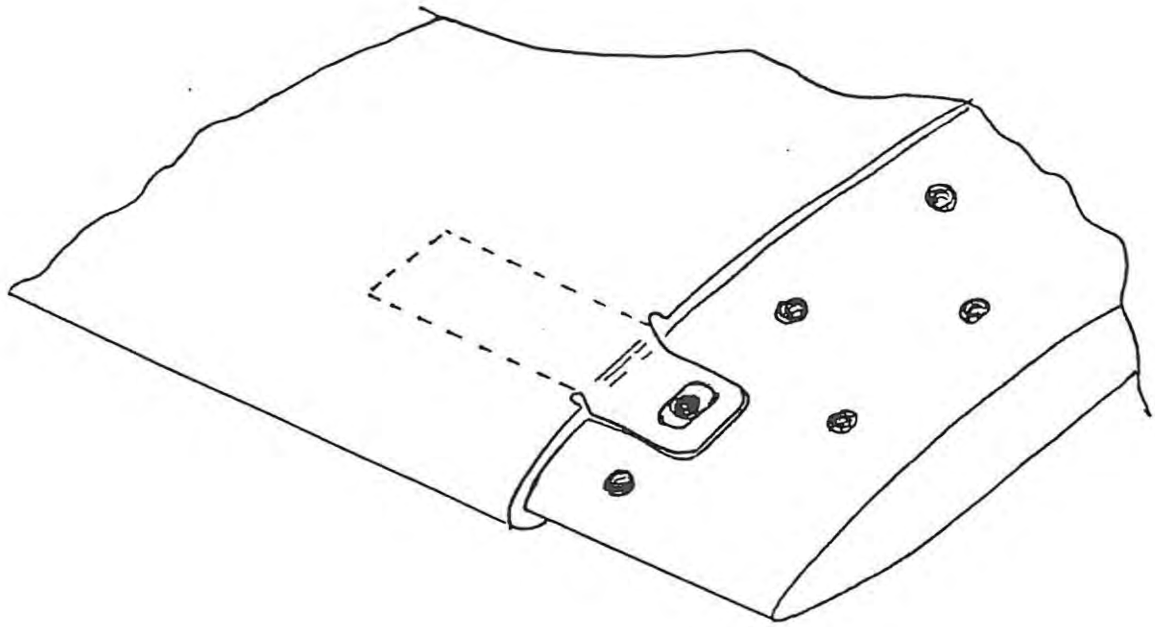
1.6.3.2 At a total number of operating hours of 2,629:05, the rotor blade was demounted and sent to Eurocopter for repair. The leading edge strip, including the de-icer element, was changed during this work which was completed on 13 March 1991. (This was 1,590 flying hours prior to the emergency landing).

1.6.3.3 On 26 April 1991, the rotor blade was fitted to helicopter S/N 332L-2048. In the period which followed, the blade underwent an 18 month inspection before being demounted on 16 January 1993 and put into storage at HS (cf. 1.18.6.6).

1.6.3.4 The rotor blade in question was removed from the HS store and modified on the basis of Eurocopter Technical Instruction No. 230 (cf. 1.6.2.5). The modification was carried out by Eurocopter staff at the HS premises at Sola. A Certificate of Release to Service for the completed modification to the blade was signed by a

FIGUR 5





representative of Eurocopter on 16 February 1995. At that point, the blade had a total operating life of 3,916:24 hours.

1.6.3.5 The rotor blade was removed from the store once again and this time fitted in the Black position on helicopter S/N 332L-2308 (LN-OBP) on 23 October 1995. LN-OBP was not fitted with de-icer equipment and, therefore, neither was the main rotor blade's de-icer equipment connected to the helicopter. (This was 303 flying hours prior to the emergency landing.)

1.6.3.6 On 9 November 1995, as a result of the blade being fitted, an inspection of the rotor blade was carried out in accordance with the Master Servicing Recommendations (abbreviated to PRE by Eurocopter) Chap. 05.41.00 (cf. 1.18.6.6) at a blade operating time of 3,959:15 hours. (This was 260 flying hours prior to the emergency landing).

1.6.3.7 The maintenance program prescribes that the same inspection must also be carried out 200 hours after a repair. Consequently, this was performed on 22 December 1995, at a blade operating time of 4,113:17 hours. (This was 106 flying hours prior to the emergency landing).

1.6.3.8 The maintenance scheduling at HS led to a 75-hour (SMC 1S) inspection and a 'Detailed check of main rotor blades, without blade tip removal' (cf.1.18.6.6) being scheduled. They were carried out at the same time. These inspections were completed on 6 January 1996, along with several others, at a blade operating time of 4,181 hours. This inspection was carried out for the main rotor blade in question with no special remarks. (This was 38 flying hours prior to the emergency landing).

1.6.3.9 On 16 January 1996, the helicopter went through a 50-hour (SMC 1S1) inspection. As mentioned in 1.18.7.4, this inspection does not contain any items relevant to the main rotor blades.

1.6.3.10 The last Daily Maintenance Check (DMC) (cf. 1.18.7.3) prior to the accident, was completed on 17 January 1996, at 24.00 hours. The inspection was carried out by 2 persons. The person with responsibility for carrying out the inspection held a technician's licence for that aircraft type and he checked the rotor blades himself. The blades were inspected from a position adjacent to the rotor head as well as from ground level. The inspection was carried out inside the hangar, without any time constraints and with no special remarks regarding the main rotor blade.

1.6.3.11 The last inspection prior to the accident was a Pre-flight Check (PFC) (cf.1.18.7.2) which was completed at 05.00 hours on the morning of the day of the emergency landing. This inspection was also carried out in the hangar with no time constraints. According to the technician who carried out the inspection of LN-OBP, there were 2 persons to inspect three helicopters, allowing time for a thorough check. The inspection of the main rotor blades was carried out from the ground without discovering anything which could give rise to any special remarks. (This was approx. 29 minutes flying time prior to the emergency landing).

1.6.3.12 The main rotor blade had a total operation time of 4,219 hours at the time of the emergency landing. Of these hours, 1,590 were flown after the leading edge strip had been replaced.

1.7 Meteorological information

1.7.1 The AAIB/N received the following general information about the meteorological conditions in the North Sea from the Meteorological Office at Bergen's Flesland airport:

Weather conditions:

Southerly air flow with a frontal zone west of the British Isles and a warm front over southern Norway.

Wind and weather:

Southerly breeze 10-15 kt, overcast, hazy and generally fine weather.

Visibility and cloud base:

Visibility estimated at 5-9 km and cloud base at approx. 1,000 ft.

Temperature:

The sea temperature was 5-6°C and the air temperature 4-5°C. Freezing level between 5,000-7,000 ft.

1.7.2 The following TAF for the period 06.00 to 15.00 UTC was issued:

ENZV 18015KT 9999 -RA SCT010 BKN020 PROB30 TEMPO 0609 5000 DZ BKN0060=

ENEK 20020KT 0100 FG VV001 PROB30 TEMPO 0615 1500 BR -DZ BKN004=

1.7.3 METAR for 07.50 UTC:

ENZV 19009KT 9999 FEW12 BKN18 04/03 Q 1024 NOSIG

ENEK 19013KT 9999 OVC006 05/04 Q1022

1.7.4 ROUTE FORECAST SOLA - EKOFISK

GENERAL SITUATION: ...... SEE SURFACE ANALYSIS

SIGN. WEATHER: .... SCT DZ/BR, FG AT SEA

WIND SURFACE: .... S-SE/10-15KT, S-LY/15-20KT AT SEA

WIND 2,000 FT: 170-200/15-25KT

WIND 5,000 FT: 200-220/20-30KT

WIND 7,000 FT: 220/25-30KT

VISIBILITY KM: .... LAN: +10KM, TEMPO 5-9KM
.... SEA: VER VIS 0100-0300FT,TEMPO
.... BKN/OVC 0300-0500FT

CLOUD TOPS: 3,000-5,000FT

+6 DEG LEVEL: .... ---
FREEZING LEVEL: FL050-FL070
-10 DEG LEVEL: FL110-130
SURFACE TEMPERATURE: .. P04-P05

ICING: .... FBL/NIL

TURBULENCE: .... FBL=

1.7.5 According to the crew, the weather conditions above the emergency landing site were:

Wind 150° 25 kt, cloud base approx. 600-700 ft, visibility approx. 6 km in drizzle, no icing. Wave height was 3-4 m.

1.7.6 The emergency landing took place in daylight.

1.8 Aids to navigation

Not relevant.

1.9 Communications

1.9.1 There is no report of anything abnormal during radio communications between the aircraft and the Air Traffic Control Service. Records of communications between the crew and the various control and information units have subsequently been made available to the AAIB/N.

1.9.2 Both pilots had two-way combined emergency radios/emergency locator transmitters (121.5 MHz) in their life jackets. No attempt was made to use these for communication because the pilots did not want to disturb the emergency location signal on the same frequency.

The Rescue Coordination Centre (HRS) states in a note after the rescue that there was no opportunity for communication with the aircraft in distress. There was therefore no radio communication between the rescue units involved and the disabled aircraft. There is no specified requirement to carry an emergency communications radio (121.5 MHz and/or 123.1 MHz, or maritime channel 16) in life rafts or on board aircraft. The 121.5 MHz and 234 MHz radio frequencies were blocked by the transmissions from LN-OBP's emergency locator transmitter (ELT).

1.9.3 The externally mounted ELT, activated by the crew, gradually drifted far away from the ditching site and transmitted signals for 2.5 days before it was located and switched off outside Karmøy (59°24.3' N and 003°45.4' E).

1.10 Aerodrome information

Not relevant.

1.11 Flight recorders

1.11.1 IHUMS

1.11.1.1 An IHUMS (Integrated Health and Usage Monitoring System) was installed in this helicopter. The system has been developed by a helicopter company in Great Britain. This is a monitoring system for both technical and flight operational parameters. The system is still under development for the Super Puma. When the system is fully developed, it is intended that it will carry out the functions of the voice recorder (CVR = Cockpit Voice Recorder), the flight recorder (FDR = Flight Data Recorder) and the HUMS = Health and Usage Monitoring System. One of the consequences of this development is that the previous Fairchild CVR has been replaced by a Penny & Giles Combined Voice and Flight Data Recorder (CVFDR). This unit is located in the helicopter's tail cone.

The recordings are made on magnetic tape in the CVFDR, and on a magnetic card which is the size of a standard credit card. This card is located in the cockpit pedestal in the Maintenance Data Recorder unit. The card contains a battery which may be discharged when the card is exposed to moisture.

1.11.1.2 The IHUMS card must normally be taken out of the helicopter by the crew to be read by a computer. This is an item on the Normal Checklist. At the time of the emergency landing, however, there was no item on the Emergency Checklist which ordered the card to be removed. Because of this, the card remained in the helicopter when it sank. The card was retrieved later together with the helicopter, but by then had been corrupted. As a result of this, the Emergency Checklist for this type of helicopter was later revised by the company, so that the card is also to be removed by the crew on ditching.

1.11.2 CVFDR

1.11.2.1 The CVFDR unit and the IHUMS card were taken to the Aircraft Accident Investigation Branch (AAIB) at Farnborough in the UK for playing and copying. In spite of the fact that the CVFDR remained with the helicopter when it sank and remained lying on the North Sea seabed for some days, the tape was, by and large, undamaged. The information from the magnetic tape gave a good picture of the flight and the course of events during the last few minutes prior to the emergency landing at sea. The FDR gave 35 readable parameters. The CVR part was of good quality and was later also played back to the crew, who explained individual details to the AAIB/N. An unsuccessful attempt was made to carry out an acoustic analysis of the recording from the area microphone with regard to technical values.

1.11.2.2 As previously mentioned, the IHUMS card was destroyed and it was therefore impossible to read any values from it.

1.11.2.3 The CVFDR was equipped with a Dukane DK 100 acoustic transmitter (pinger). This transmitter should normally transmit on a frequency of 37.5 ± 1 kHz. The transmission is started by a water-activated switch. Examinations which the AAIB/N has had carried out at Dukane, however, showed that the unit was transmitting on a frequency of 38.8 kHz when it sank. The search for the helicopter was initially based on the transmission from the acoustic transmitter. The change in frequency led to the introductory phase of the search for the helicopter on the seabed being unsuccessful, since the search equipment was searching in the area of frequencies of 37.455-37.545 kHz.

1.12 Wreckage and impact information

1.12.1 The accident site

In the North Sea, approx. 25 NM off the coast, out of Egersund (58° 14' N, 005° 09' E).

1.12.2 The helicopter wreckage

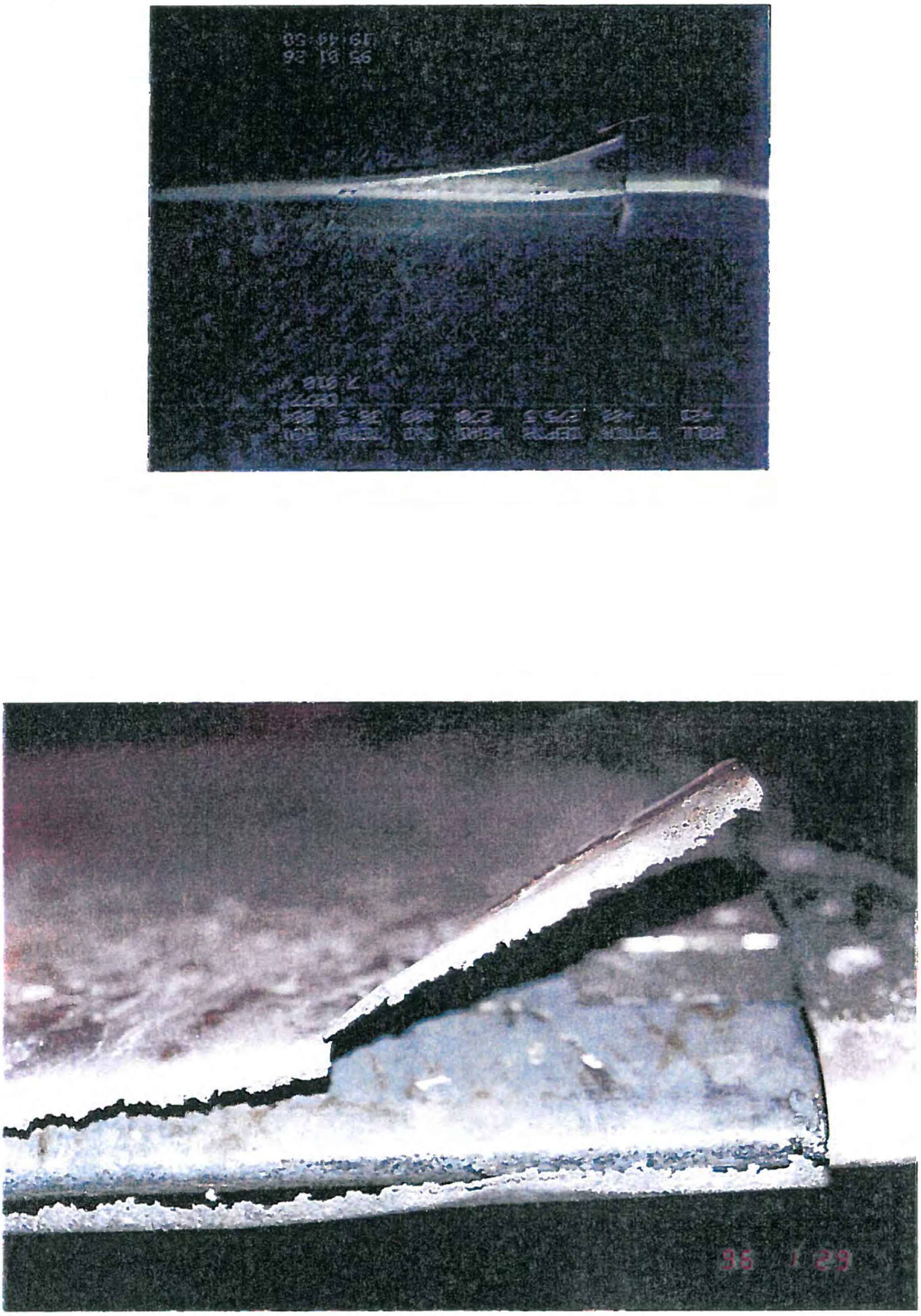
1.12.2.1 After the evacuation, the helicopter remained floating on the sea. The Coast Guard vessel KV Farm and a rescue cutter went to the scene of the accident, and work began on securing and making the helicopter ready for salvaging. Personnel from HS who arrived on the boat via helicopter and the Coast Guard used an outboard dinghy to place two inflated floats inside the cabin and to fit winching straps to the main rotor head. During this operation, the helicopter was photographed and it was determined that the "black blade" (S/N 617) was damaged (see Figure 6).

1.12.2.2 The weather deteriorated during the evening of 18 January, and when the salvage vessel "Geomaster" arrived at the scene of the accident at approx. 24.00 hours, four hours late, there was a stiff breeze and the wave height was 7-8 m. The helicopter capsized before the salvage work could commence, and remained floating on the surface, bottom up, without it being possible to continue with the work. The helicopter sank on 19 January, at approx. 17.00 hours. The search for LN-OBP using a hydrophone was begun from the "Seaway Condor" on 23 January. This produced no results and the decision was taken to search using sonar. Subsequent investigation of the helicopter's acoustic radio beacon showed that it was transmitting on a frequency which was outside the specifications, and that it was beyond the frequency area of the search equipment on the Seaway Condor. The helicopter was located on 27 January at a depth of approx. 285 m, 114 m east of its last known position. LN-OBP was found lying with its nose and the upper part of the cockpit roof sunk into the seabed, and with three of the main rotor blades snapped. The main rotor blade, S/N 617, had not snapped and the damage at the blade tip was videoed for documentation before dismantling work began (see Figure 7A). The blade in question was dismantled first and brought up to the salvage vessel. After that, the three remaining blades were dismantled. The helicopter was then turned round and hoisted on board the Seaway Condor. Work on the seabed was carried out by means of Remote Operated Vehicles (ROVs). These had increasing problems in manoeuvring in the strong underwater currents which arose. This led to the salvage operation being concluded without the three remaining blades being brought up.

1.12.2.3 The helicopter remained relatively undamaged after its emergency landing on the sea. The crew stated that none of the main rotor blades touched the sea before the main rotor stopped. The helicopter, however, sustained considerable damage after it turned over and then sank. The great pressure at a depth of 285 m crushed components and parts of the structure flat where water was not able to penetrate sufficiently quickly to equalise the pressure. In this way, the main rotor blades sustained compression damage in the honeycomb structure. The impact with the seabed led to a depression of the nose and the cockpit section, and the salvage of the helicopter led to further damage. The time spent in salt water, a period of 9 days, led to large-scale corrosion damage on several of the helicopter's vital parts.

FIGUR 6

FIGUR 7 A/B



1.12.2.4 The helicopter and the rotor blade were examined by the AAIB/N after they were brought into the HS hangar at Sola. During this work, no faults or discrepancies were discovered in the helicopter which could not be explained by damage which arose during the emergency landing, sinking and the subsequent salvage work.

The main rotor blade (S/N 617) was transported to the premises of Det Norske Veritas (DNV), at Høvik, for closer examination by DNV in collaboration with the AAIB/N.

1.13 Medical information

The crew members were not suffering from any medical conditions which would have been of any significance to this emergency landing.

1.14 Fire

There was no fire in connection with the emergency landing.

1.15 Survival aspects

1.15.1 General information

1.15.1.1 The crew of LN-OBP carried out a controlled emergency landing in the North Sea during winter. On that occasion, the wind and wave height were moderate and the sea temperature was a few degrees above zero. After the success of performing the landing at sea, passengers and crew were starting with a good basis for rescue as a result of a rapidly executed rescue operation. This was carried out quickly and efficiently by the rescue helicopters scrambled from the airport at Sola.

1.15.1.2 The helicopter was fitted with emergency equipment for offshore flights as required by the aviation authorities. The helicopter was, in accordance with regulations, equipped with emergency flotation gear, and after this was inflated just prior to landing, the helicopter remained afloat for a long time. Details of the emergency equipment are given in the Norwegian Civil Aviation Regulations (*Bestemmelser for Sivil Luftfart*) (BSL) D 2-2, points 5.2 and 5.5 plus relevant parts of BSL D 2-1 with the exception of items indicated in BSL D 2-2, point 3.1. This states that there should be life jackets for everyone on board (plus spares), sufficient numbers of life rafts to carry everyone on board and an emergency radio beacon (emergency locator transmitter). No specific requirements have been set for the life rafts. Requirements for the crew's obligations in emergency situations and for their emergency training are contained in BSL D 2-1, point 9.3 and 9.4.

1.15.1.3 The passengers were equipped with insulated survival suits of varying standards. The civil aviation authorities have not set specific requirements for this.

The crew were wearing non-insulated survival suits. Over these, they were wearing blue cotton flying suits. There is no requirement, on the part of the aviation authorities, for the crew to wear survival suits.

1.15.1.4 The joint European regulations JAR-OPS 3, to be issued soon, state that any company which wishes to carry out flights of more than 10 minutes flying time from land, across water, must equip the crew with survival suits when the sea temperature is below 10°C. It is stressed that attention must be given to the insulation capabilities of the suit and to the type of clothing which is being worn under the suit. The purpose of this is to take account of the total insulation ability which the suit and underclothing have, to permit survival in water until a rescue vessel has reached and rescued the person. The suit must be equipped with an insulated hood.

1.15.1.5 Whether it is the public authorities who are involved in oil production or the operators, the parties involved in oil operations in the Norwegian sector of the Continental Shelf are concerned with the safety of those who are working offshore. The personnel are thoroughly checked and trained onshore before they are allowed to travel out to the installations. They are provided with a survival suit and receive information from their employer about how they should be dressed under the suit. This concern with personnel safety is primarily directed towards work on the offshore installations. The interest in safety details is not so strongly developed in the oil operators with regard to the transportation phase (the in-transit phase). This is regarded by the operators as the responsibility of the civil aviation authorities. Furthermore, the Norwegian Petroleum Directorate has determined that the transportation part (the helicopter flight) falls outside the Norwegian Petroleum Act (*petroleumsloven*).

1.15.1.6 Before each flight, the passengers are shown a video which deals with different subjects of importance to safety during transportation. After they have boarded the helicopter, the passengers receive safety information from the crew before departure.

1.15.2 Evacuation

1.15.2.1 After it had been decided that an emergency landing would have to be performed, the passengers were made aware of this by the Pilot-in-Command via the aircraft'sg to ditch in the sea. Everyone must prepare themselves for this. Do up your suits and pull your hoods over your heads. This will be a controlled landing."

This was not the full briefing which, according to the crew's Emergency Passenger Briefing checklist, should have been given to the passengers. This list includes the passengers' use of safety belts, the removal of spectacles and similar details. The checklist concludes with a short piece of information about the sitting position prior to an emergency landing. Use of a life jacket is not mentioned in the list. However, this is something which is indicated in the printed safety information notice which is located in the seats.

1.15.2.2 After the announcement, some of the passengers took out their life jackets, and some began to put them on. This led to most people attempting to do this, but with varying success. It proved to be fairly difficult to put on life jackets over hoods and on top of the survival suits. Another situation which became relevant was that the headsets had to be removed. After these were taken off and the hood on the survival suit pulled up, it was more difficult for the passengers to follow the announcements/ information issued by the crew.

1.15.2.3 From the cockpit, after the Pilot-in-Command had stopped the rotor, he electrically armed and released both life rafts. These were located in the sponsons, one on either side. The Pilot-in-Command electrically released the ELT, which was mounted on the fuselage. This then began to transmit emergency signals automatically at 121.5 MHz. This is not in accordance with the emergency checklist which states that the ELT should be in the 'Activate' mode.

1.15.2.4 The helicopter, which was afloat in a stable manner on the sea, had gradually positioned itself sideways on to the wind so that the port side was in the lee. It may appear that the sea anchor was to little effect. The purpose of the sea anchor is to hold the nose of the helicopter up into the wind. On its release and inflation, the starboard life raft was caught by the wind and blown up onto the roof of the cabin, where it became lodged under a rotor blade. To begin with, the port life raft was located correctly outside the port cabin door.

1.15.2.5 After the helicopter had come to rest in the sea and the sea anchor was released, the Co-pilot left the cockpit. He had put on his life jacket which contained an emergency radio. He did not inflate the jacket. The Co-pilot took the first aid box and the portable emergency locator beacon with him. He positioned this at the port cabin door. The Pilot-in-Command had decided that the cabin doors should not be released, but that both should just be opened. The Co-pilot therefore opened the port cabin door by pushing it fully forward and locking it in this position. Doing this blocked the forward, port side window emergency exit. The other windows, which can be released from the inside, were opened.

1.15.2.6 The Co-pilot took up a position at the port cabin door and ordered an evacuation into the port life raft. The first passenger took the emergency locator beacon with him. Gradually, all 16 passengers and the Co-pilot boarded this raft. The raft was continually striking the side of the helicopter at the same time as it was gradually drifting backwards and under the tail boom. When the raft went under the tail boom, the passengers were forced to the opposite side of the raft, which after a time led to space being very cramped. Because of the movement of the helicopter in the waves, the tail boom was regularly striking the raft. Several of the passengers and the

Co-pilot tried to hold the raft away from the helicopter, but were unable to do so. They also found it very difficult to retain a firm hold on the outside of the helicopter. Finally, the raft had been struck so much by objects protruding from the tail boom that one of the tubes of the raft became punctured. This led to some of the passengers and the Co-pilot falling into the water, and a significant amount of water coming onto the floor of the raft. One passenger was left hanging on the tail boom, but managed to get free and was helped into the raft again. At this point, the Co-pilot ordered everyone to return to the cabin of the helicopter. After something of a struggle, all 17 managed to do this. Most re-boarded the helicopter straight from the raft, while others swam back and had to be lifted up out of the sea.

The port raft was regarded as unusable after this. Many of the passengers had put on their life jackets at this point, while others were still holding them in their hands. Some of the survival suits had flotation chambers in the upper part. No-one remembered to inflate this chamber in their survival suit. The passengers were dressed in different types of suit depending on the company for which they were working. The suits kept the passengers more or less dry and warm, apart from those passengers who were dressed in suits which did not incorporate boots. The feet of these passengers became very cold after a short time.

1.15.2.7 When the Pilot-in-Command saw how the situation was developing for the passengers on the port side, he opened the starboard door and climbed up onto the sponson. He attempted to release the starboard raft which had been blown up onto the side/roof of the helicopter. Several lines/ropes from the raft had got entangled in a strong tie-down hook on the side of the fuselage. Only after having cut these did he manage, with great difficulty, and with the help of one of the passengers, who had by then returned from the other raft, to release the raft and launch it into the sea. Because the lines had been cut, this raft was no longer attached to the helicopter. The Pilot-in-Command, and the passenger assisting him, jumped down into the raft to stabilise it beside the starboard cabin door. For a short time, they managed to hold it in against the helicopter manually. Two more of the passengers, who had returned to the helicopter, were able to jump down into the raft before it drifted away. The drift of the helicopter in the sea continued to be greater than that of the raft, but since this raft was now on the windward side, the effect was the opposite to what would have happened on the port side. On this side, too, it was difficult to find anything to hold on to on the outside of the helicopter. An attempt was made to throw a lifeline from the raft back to the people standing at the door opening, but without success. The starboard raft finally drifted away from the helicopter with four men on board. When they saw that it was not possible to reboard the helicopter, they began to raise the canopy over the raft. After this was set up, the raft and the helicopter drifted at approximately the same speed. This raft remained at a distance of approx. 100-200 m from LN-OBP.

1.15.2.8 The Co-pilot and 13 passengers remained inside the helicopter. They were dependent on the helicopter's ability to float and their own survival suits and life jackets. The atmosphere on board was good in spite of the water now being approx.

30 cm above the floor. The Co-pilot informed the passengers that the rescue operation had commenced, and that rescue could be expected soon.

The helicopter's fuel tanks are located under the floor. Fuel was pushed up by the tanks through the tank vent, and it mixed with the sea water in the cabin. Combined with the wave motion, this led to many of the passengers in the cabin being seasick.

1.15.2.9 Another transportation helicopter (a Super Puma from Norsk Helikopter AS, NOR 005) arrived at the site of the emergency landing. It hovered close by, and although this helicopter had no capacity for rescuing anyone, the passengers felt this to be positive support, even if a few found the noise disturbing with regard to being able to talk amongst the

1.15.2.10 Passengers have stated that they noticed that the crew members were cold, especially the Co-pilot who had been in the water. One of the passengers who had been talking to the Co-pilot said that he was "soaking wet in the black cotton uniform and his teeth were chattering".

1.15.3 Rescue service

1.15.3.1 The Ministry of Justice and the Police is responsible for administrative coordination of the rescue service and the two Rescue Coordination Centres (HRS). The 55 local rescue centres and 16 aircraft rescue centres are responsible for the operational coordination of the rescue service.

1.15.3.2 The two HRSs are located in Stavanger and Bodø. They each have overall responsibility for coordination within their own part of the country, south and north of a latitude of 65°N, respectively.

Each HRS has a rescue management team consisting of the Stavanger and Bodø police chiefs, respectively, as chairman, together with representatives from the Norwegian armed forces, Telenor [the Norwegian telecommunications operator], the Air Traffic Control Services and the Public Health Service. In addition, a number of advisers have been appointed to be called in as required.

Full-time employees are: 1 rescue inspector and currently 12 rescue officers and administrative staff at each HRS. The rescue inspector is the general manager, and the rescue officers man the centre 24 hours a day.

The HRSs are equipped with communications equipment, and are in direct contact with all important partners within the rescue service.

1.15.3.3 On 18 January 1996 at 08.43 hours, the alarm was raised at the HRS for southern Norway by Stavanger Air Traffic Control Centre (ATCC) regarding the transmission of an emergency message by LN-OBP, and at 08.44 hours a request for search and rescue was forwarded to the rescue helicopter service at Sola airport.

1.15.3.4 The Norwegian Air Force runs the rescue helicopter service (330 squadron) with 10 Westland Sea King helicopters. These are stationed at the airfields at Sola, Ørland, Bodø and Banak. At each of these locations, a helicopter is on one-hour standby all year round. This helicopter is at the exclusive disposal of the HRS. Sea King helicopters are equipped with two engines, two rescue winches and systems for automatic hovering. With few exceptions, they can operate above the sea in all weather conditions both day and night. With a capacity for rescuing up to 18 people in distress and with an operational radius of 230 NM, these helicopters should be able to reach people in distress inside the operations area within a 1.5 hour direct flight from their standby base.

1.15.3.5 At the time of this emergency landing, which took place just after the normal working day had begun at the rescue squadron, a full operational crew happened to be present. The rescue helicopter was therefore able to leave Sola just 11 minutes after the alarm was issued by HRS, heading towards a given position of 58°14.6' N and 005°06.0' E. There was also supposed to be a doctor present, but he had not arrived at this time. It was decided that he could go with a second helicopter which departed 18 minutes after the first. HRS procedures for notifying the Sea King doctor vary somewhat inside and outside normal working hours. The HRS is of the opinion that there are too many variations in notification procedures and communications options. The aim must be notify the doctor rapidly and for the doctor to be able to communicate on medical matters when required. It was also fortuitous that there were two fully crewed and equipped rescue helicopters available at Sola shortly after the time of this emergency landing.

1.15.3.6 A little less than 1 hour from the controlled emergency landing in the North Sea, the first rescue helicopter arrived at the emergency landing site. From the helicopter, a member of the rescue team was winched down into the sea with a line. He swam over to the helicopter and took up a position on the port sponson with the Co-pilot. From the door opening, the passengers were winched on board one by one. After the first winch, the passengers were taken up in the harness two at a time. Finally, all 13 passengers and the Co-pilot were winched safely on board the rescue helicopter.

1.15.3.7 As this was going on, the second rescue helicopter arrived. Without problem, this helicopter rescued the three passengers and the Pilot-in-Command from the starboard life raft.

1.15.3.8 After all of the passengers and the crew had been winched on board, both rescue helicopters flew to Stavanger's Sola airport, where they landed at 10.14 hours and 10.19 hours respectively. The passengers were looked after. They were eventually all taken to a hotel at the airport. Here they were met by various teams, and the events, the emergency landing and the rescue mission were examined in detail. The police were present at the hotel and took statements from the crew and passengers.

1.15.4 Rescue equipment

1.15.4.1 The company has equipped the AS 332L1 helicopter with the following emergency equipment (see Figure 8):

1 box containing first aid equipment
2 fire extinguishers
3 torches
1 life jacket per seat plus an extra 4
2 life jackets for the crew in the cockpit
1 portable emergency locator transmitter (ELT), also called ELB-A/ELBA
1 fuselage-mounted emergency locator transmitter (ELT, also called CPI)
4 extra survival suits (lightweight type)
2 life rafts (externally mounted)
1 plastic-laminated illustrated safety information sheet at each seat.

The crew life jackets contained a combined emergency radio/emergency beacon, distress flares and safety lights.

In addition to this equipment, each passenger was supplied with a survival suit by his/her employer/principal. These were of varying design and were supplied by various manufacturers. The oil operators determine the type of suit which oil workers are to be equipped with. They are all approved by the Norwegian Directorate of Shipping and Navigation.

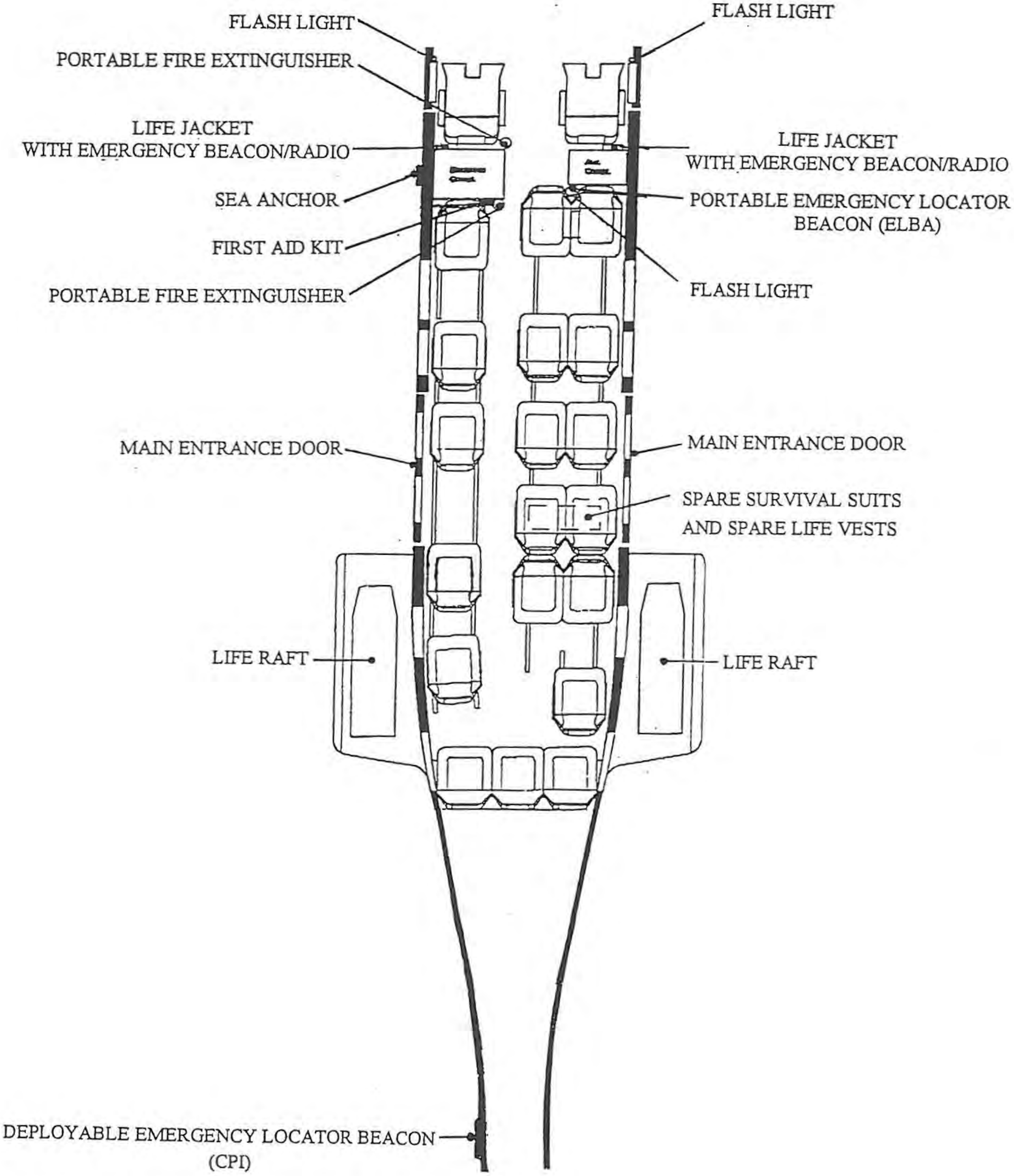
There is also a pack containing rescue equipment in each of the life rafts.

According to the Pilot-in-Command, there were no paddles, which should have been on board the raft according to the raft equipment list and the emergency training course at NUTEC. The company, however, stated that the paddle had been removed as much as five years previously.

1.15.4.2 The members of the crew were wearing blue non-insulated flying/survival suits. Neither of them was dressed in particularly warm insulating garments under the suit, and this led to both of them quickly becoming cold and beginning to become hypothermic in the low temperatures outside the helicopter. This is especially so of the Co-pilot, who had fallen into the water.

FIGUR 8

EMERGENCY EQUIPMENT LN-OBP



FOR EACH PASSENGER SEAT: LIFE VEST AND SAFETY ADVISOR

1.16 Tests and research

1.16.1 General description of the manufacture and repair procedure for de-icer main rotor blades

1.16.1.1 The main rotor blades are manufactured and repaired by Eurocopter, of La Courneuve in France, but the blades' de-icer elements are produced by a subcontractor, Paulstra, of Chateaudun, France.

1.16.1.2 According to the information supplied by Eurocopter, the ready-moulded leading edge strips made of T-40 were subject to caustic oxide cleaning and sent to Paulstra. Paulstra received the strips and degreased them using methyl ethyl ketone (MEK) before they were wiped clean with rags and rubbed down internally using grade 100 paper and hot water. The leading edge strip was then wiped clean with rags and was checked using water (water break test) to see that all grease had been removed. If everything was found to be within the requirements, the strip would be dried and a layer of primer (Primer I, grey) applied by brush. After a drying period, a new layer of primer would be applied (Primer II, black) by brush and, after another drying period, the thickness of the primer layers would be checked.

1.16.1.3 Paulstra also manufactures the heating elements and the electrical conductors for the de-icer element. These are embedded in neoprene and reinforced with a fibreglass sheet in a vacuum/heat process (autoclave). A layer of neoprene was then laid on top of this mat containing the heating elements. This was followed by the leading edge strip with the primer layers. This was again processed in an autoclave so that the neoprene and the heating element would become vulcanised to the leading edge strip. In order to verify the quality of the vulcanisation, Paulstra prepared a trial piece in parallel during the vulcanisation process. This was then tested using destructive tearing tests. In addition, the de-icer elements were tested and the heating which this involved would reveal any blisters in the vulcanisation. The finished leading edge strip containing the de-icer elements was then returned to Eurocopter for installation on the main rotor blades. These main rotor blades could be manufactured new, or they could be old blades which had been returned to the factory for overhaul/repair, and from which the old leading edge strip and de-icer elements had been removed. Eurocopter carried out final checks of the condition of the vulcanisation of the leading edge strips by means of a tapping test (see Appendix 2).

1.16.1.4 During a visit which the AAIB/N and DNV made to BEA/Eurocopter in September 1996, Paulstra provided some background information on and a demonstration of the manufacturing process for leading edge strips with de-icer elements. It was then stated that the process had basically remained unchanged since the leading edge strip for blade S/N 617 was manufactured. However, there had been two minor changes. In 1995, Eurocopter switched to sandblasting the leading edge strips before they were delivered to Paulstra, and Paulstra had improved the checks on the thickness of the two layers of primer which were applied prior to the vulcanisation process. As presented to the AAIB/N, the manufacturing process gave the impression of great attention to detail.

1.16.1.5 After the accident, in collaboration with BEA, Eurocopter wanted to examine the effect of glycol and salt water on samples vulcanised in the same way as were main rotor blades with titanium leading edge strips. The tearing tests showed that the binding was not weakened after a sample piece had been submerged in glycol for 5 days at room temperature. The same situation was repeated with a sample in salt water under the same conditions. The sample was torn up and the neoprene separated. According to the information provided by Eurocopter, it was possible, however, to pull the remaining rubber and the two layers of primer away from the titanium sheet manually 7 days later.

1.16.1.6 To enable the AAIB/N to improve its knowledge of vulcanisation, contact was made with Trelleborg Viking in Mjøndalen. This company has long-term experience of vulcanising rubber to metals. It provided the information that the precise bonding mechanism in a vulcanisation process has not been fully charted, but that a chemical reaction occurs between the metal molecules and the primer molecules. At the same time, a chemical bond occurs between the primer molecules and the rubber. This gives a chemical bond between the metal and the rubber effected by the intermediate layer(s) of primer. Optimal contact will occur if the metal surface is completely clean and polished. This is difficult to carry out in practice, so the degreasing and cleaning process used during procedures such as glass-blowing, is usually used. On questions regarding the possible fault mechanism, the following possibilities were raised:

- Wrong treatment of the metal surface (lack of degreasing, faulty removal of oxide deposits, wrong degree of roughness, pollutants applied during the blasting process or high levels of moisture)
- Too long a time between cleaning the surface and applying the primer (new oxidation, pollutants or moisture deposit)
- Faults in the primer or not suited to the metal and rubber
- Faults during the application of primer (age, viscosity, stirring, thickness of application, applied pollutant and observance of drying times)
- Faults in the rubber (age, cleanliness, even thickness without holes and faults)
- Poor temperature and humidity control during the work processes
- Air trapped between metal and rubber
- Faults in the vulcanisation process (pressure, temperature and variations in these).

In connection with questions about possible influences which might weaken otherwise good vulcanisation, the following points were mentioned:

- Operating temperature too high during use
- Intrusion of chemicals which destroy the bonding
- The rubber is exposed to chemicals which destroy the rubber or cause it to swell
- Dynamic stresses may degrade the bond over a period of time
- The metal alloy may contain materials which degrade the bond.

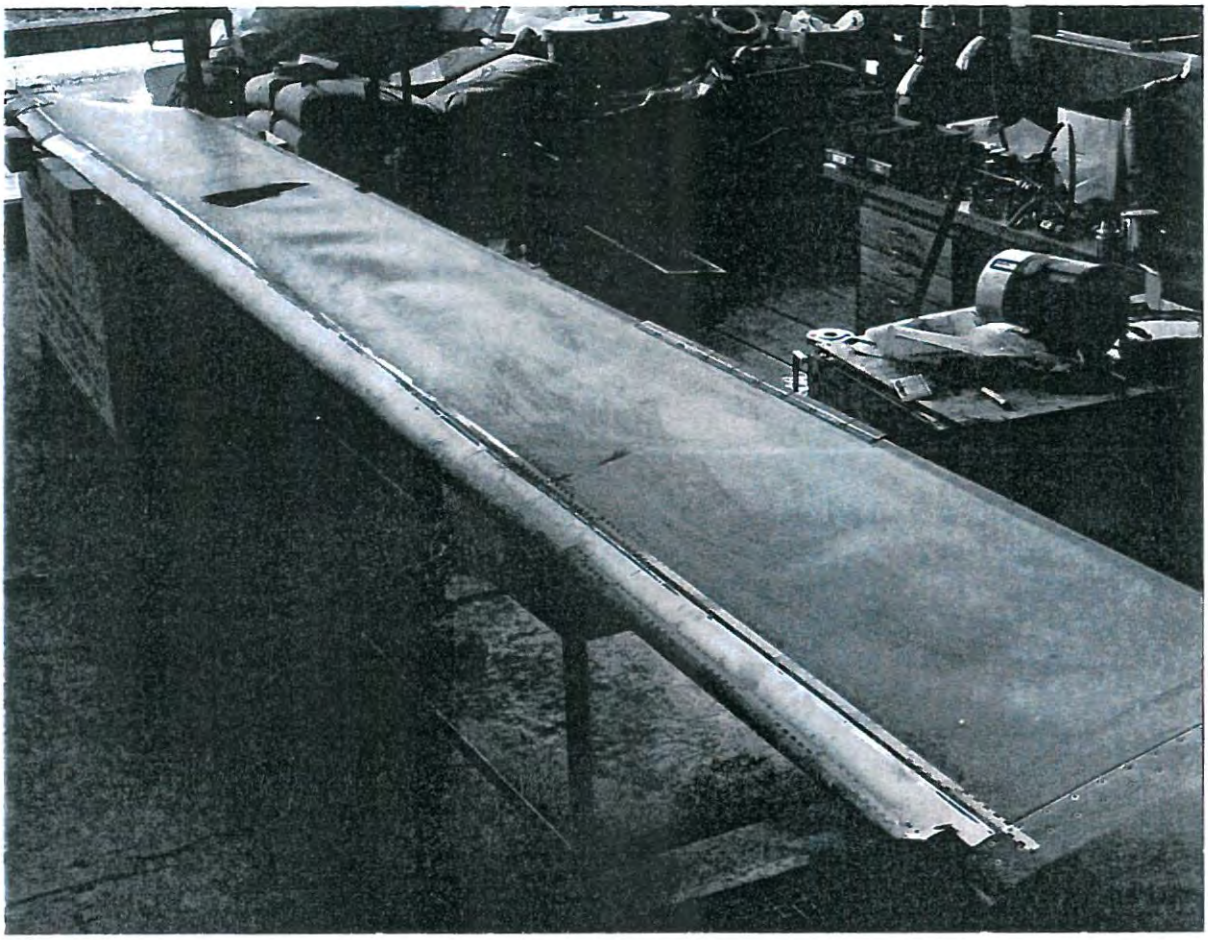
Information was also given about the great difference in the durability against sea water of various types of neoprene.

1.16.2 Visual description of main rotor blade S/N 617 after the salvage work

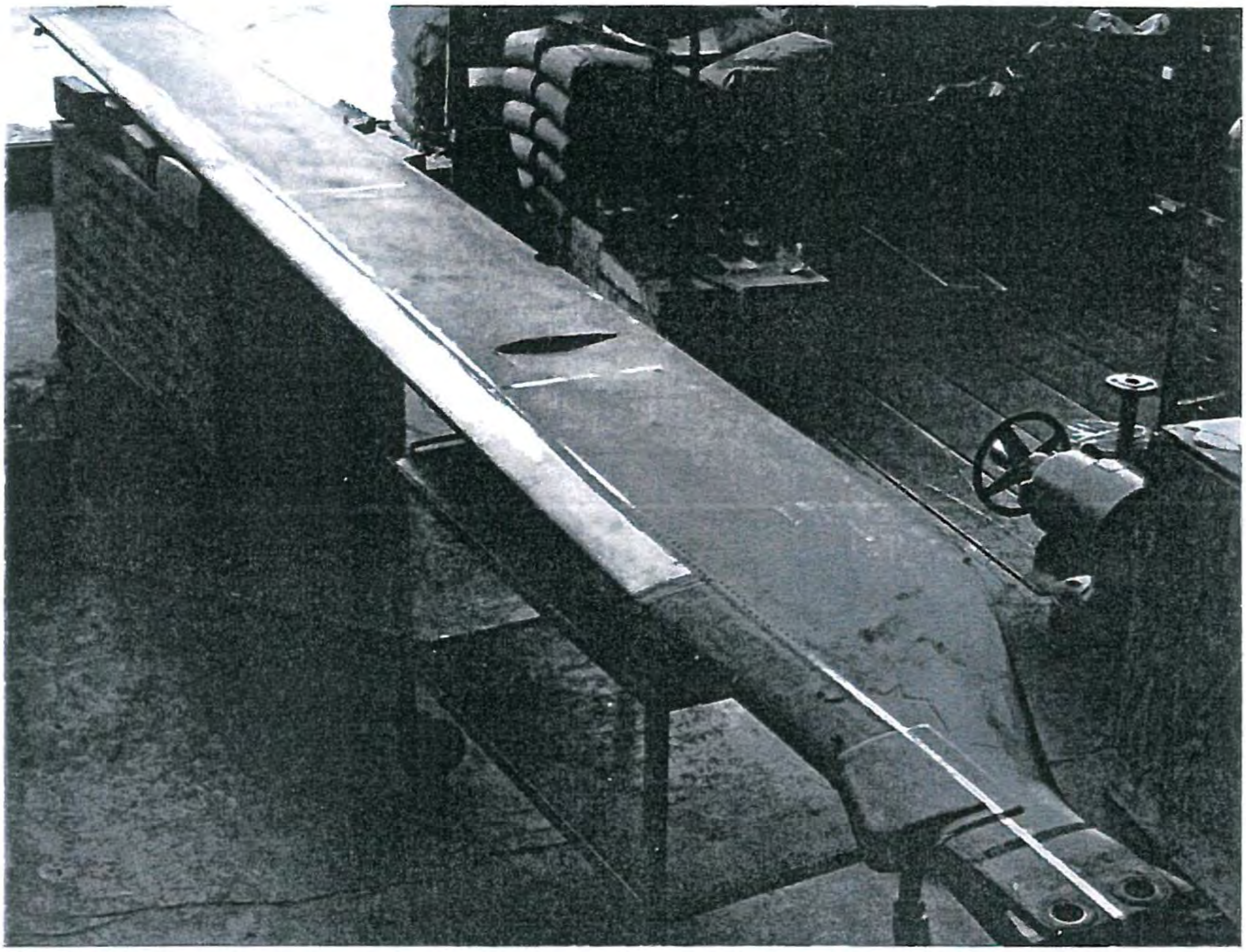
1.16.2.1 The main rotor blade sustained considerable water pressure damage when it sank in a water depth of approx. 285 m along with the helicopter. The air-filled honeycomb core was compressed in such a manner that the entire blade, including the leading edge strip, was affected. As illustrated in the pictures in Figure 9 and Figure 10, the pressure also forced holes in the skin of the blade. The damage to the skin of the blade led to water flowing into the core of the blade so that pressure was equalised and the blade largely regained its original profile. When the blade was received by the AAIB/N, the core of the blade was soaked with water. The water pressure had led to parts of the structure in the leading edge of the blade becoming loosened from the core of the blade (see Figures 11A-12B) on the upper side approx. 180-320 cm from the zero line. From 317-537 cm from the zero line (see Figures 12B-14A), the structure at the leading edge had also given way, but the leading edge strip had loosened from the underlying de-icer element (the transition zone is marked with an arrow on Figure 12B).

1.16.2.2 The blade sustained other damage as a result of the accident and the subsequent salvage work. The AAIB/N chose to disregard this damage since it is not significant to the accident, but thoroughly examined the outermost 1 m of the blade with the support of DNV.

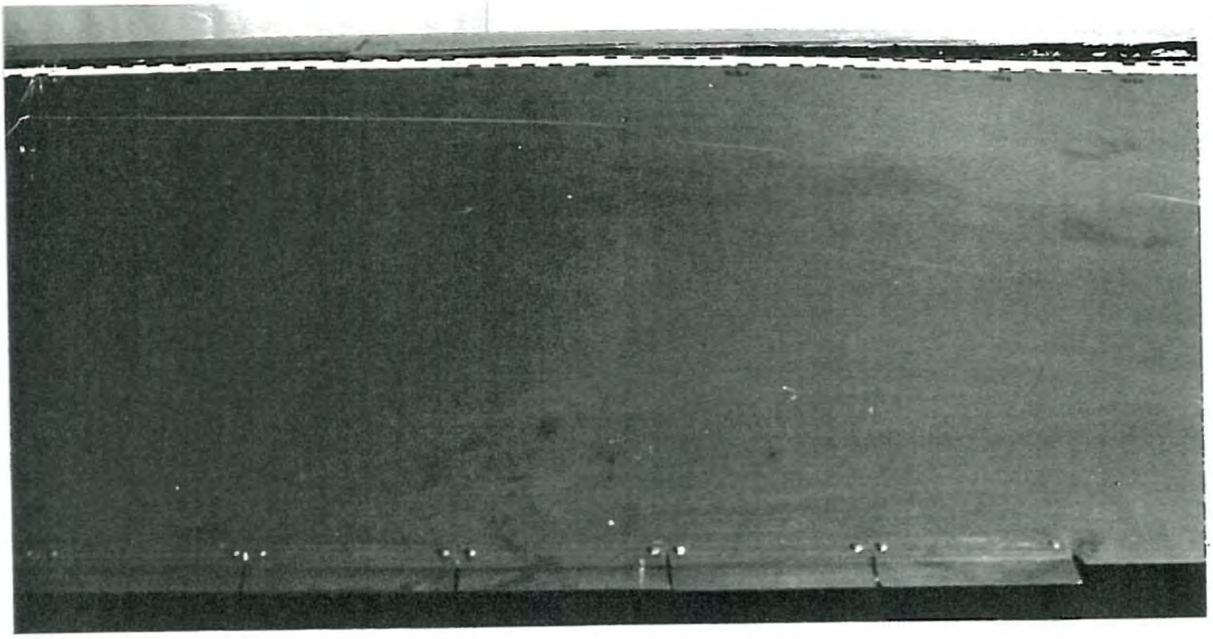
1.16.2.3 Along the outermost 285 mm of the blade, measured from the zero line (see Figures 15B-16B), the leading edge strip had an open crack (hereafter called the main crack). A section on the upper side of the leading edge strip became folded up for a length of 75 mm and at an angle of approx. 22° (see Figure 17). The sketch also shows a rectangular piece removed from the leading edge strip (cf. 1.6.2.5 Eurocopter Technical Instruction No. 230). Cracks have radiated out from the corners of this cut-out section. The sketch also shows that, altogether, 8 transverse cracks have radiated from the main crack along the leading edge strip. The fold which lifted away from the base layer has been folded along a 55 mm line stretching from one of the transverse cracks to a crack starting at the back corner of the cut-out.



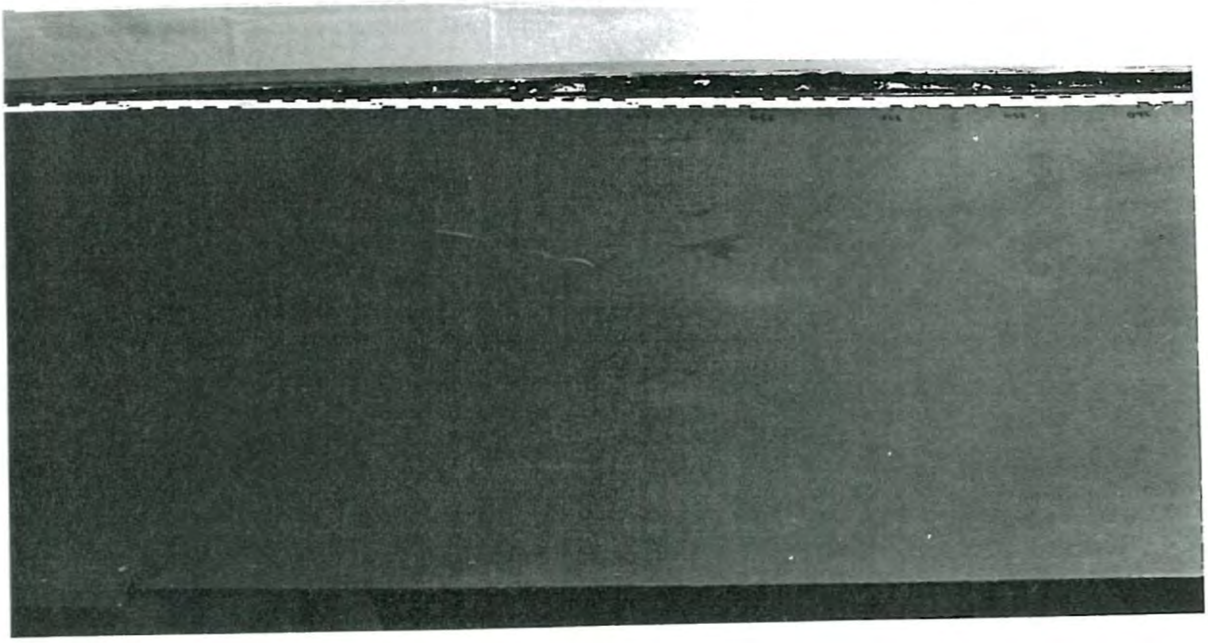
General view of the upper surface of the failed main rotor blade. The tip cap is seen down to the right. Adjacent to this cap a local section of the protective Ti-strip is seen deformed by bending (lift separation).



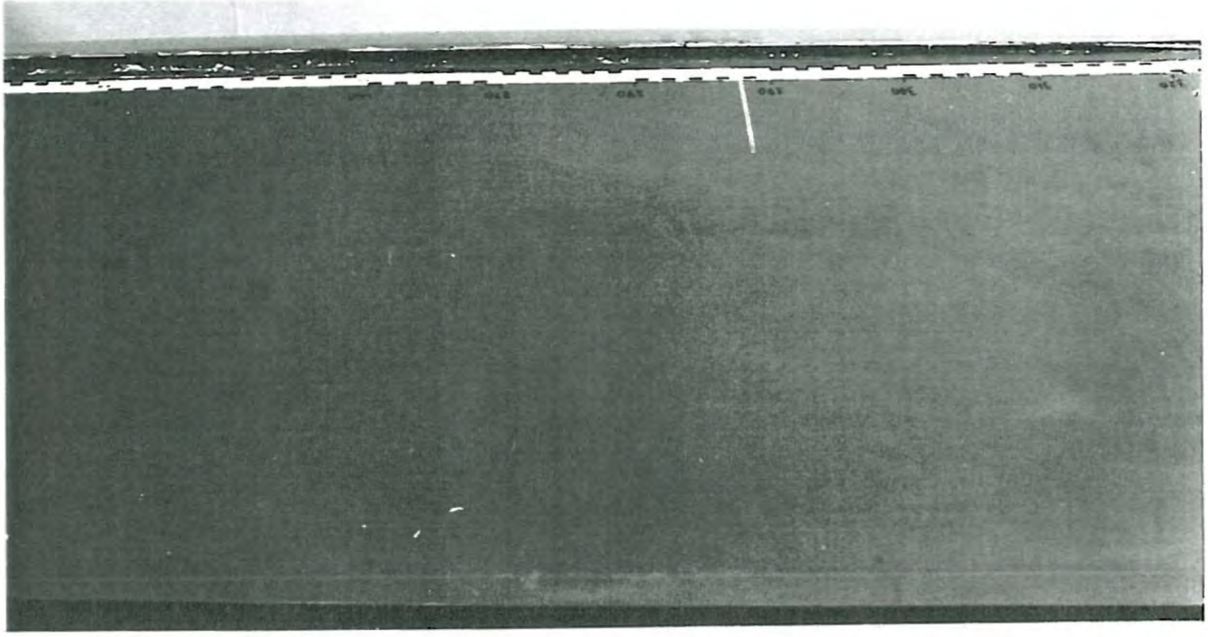
General view of the lower surface of the failed main rotor blade. The outer end of the blade is located at the top of the photo.



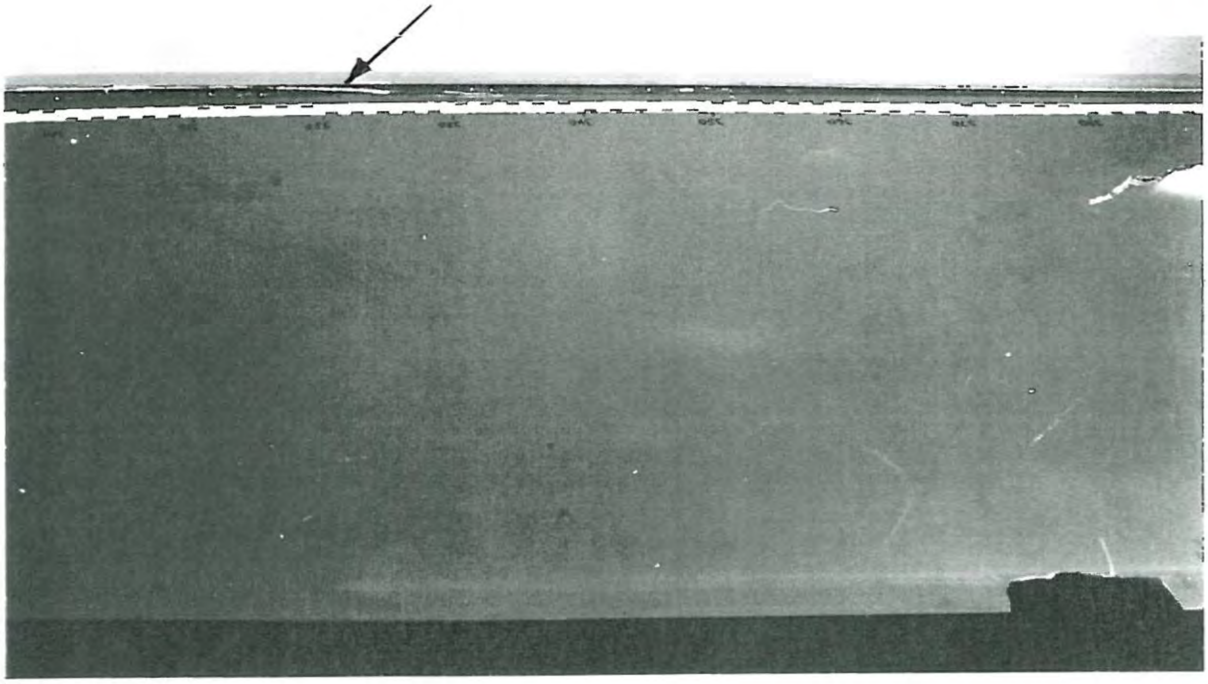
MRB upper surface 1.3 - 2.1 m away form the "zero line", seen towards the leading edge. Separation between the protective Ti-strip and the underlying skin is noted, as well as internal skin separation by rupture (seen uppermost).



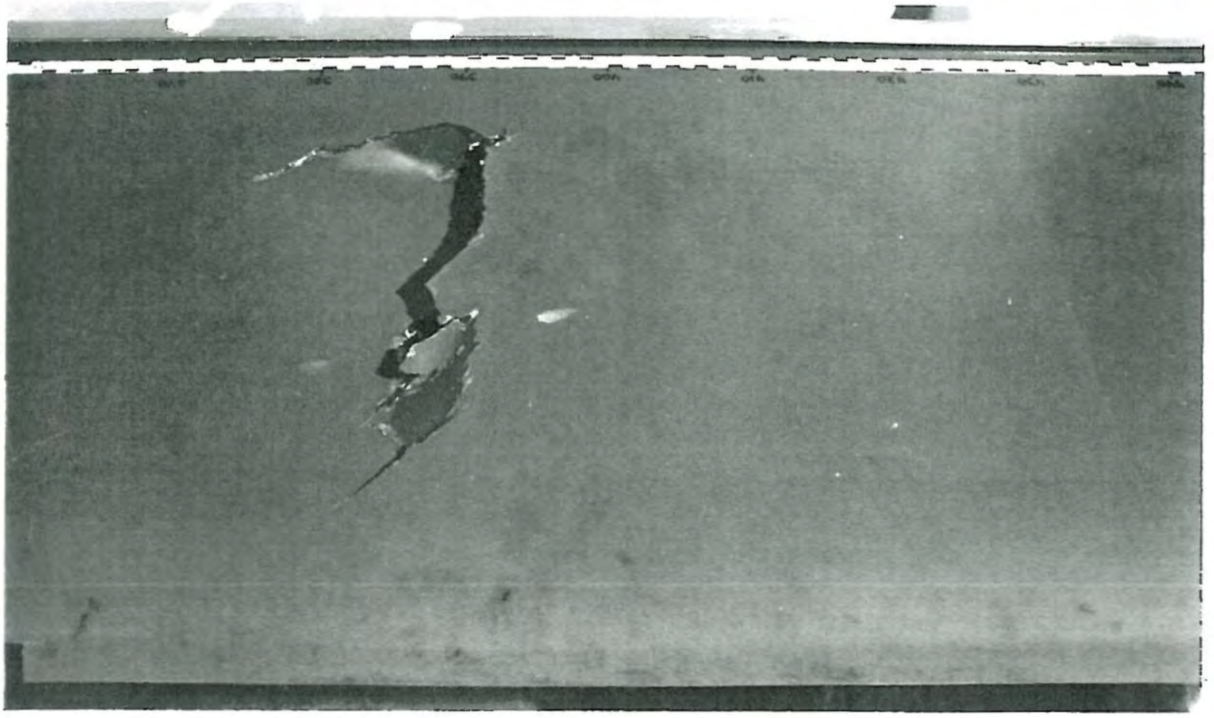
MRB upper surface 1.8 - 2.6 m away from the "zero line", seen towards the leading edge. Internal skin separation by rupture below the protective strip is noted.



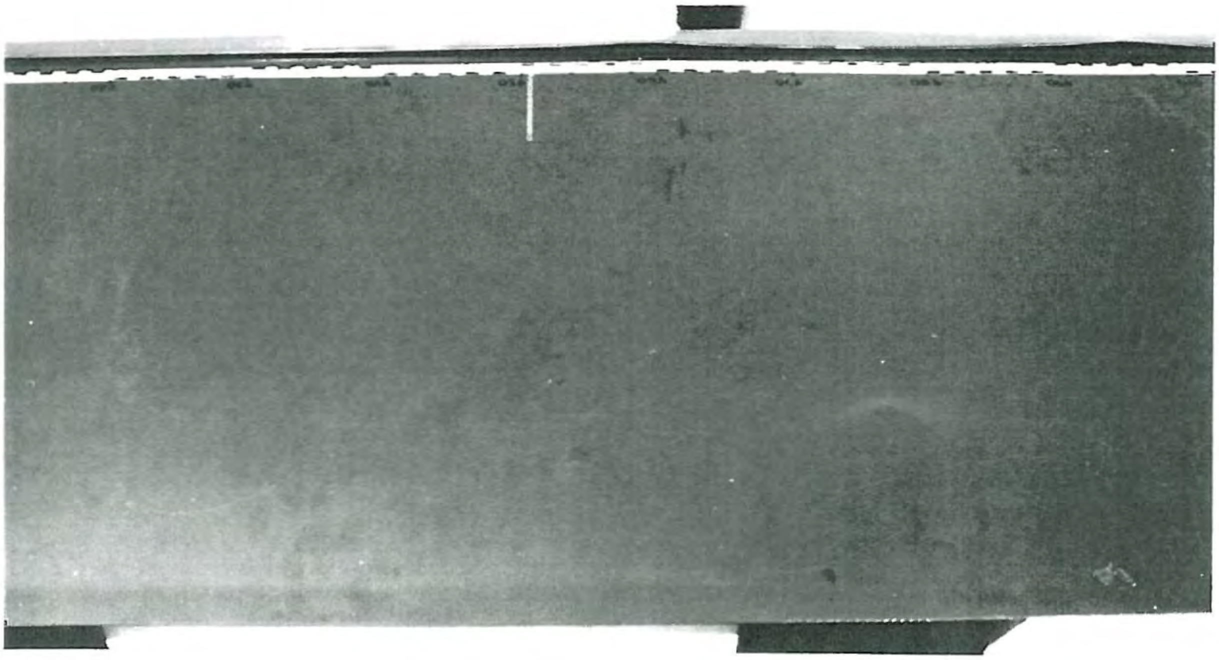
MRB upper surface 2.4. - 3.2 m away from the "zero line, seen towards the leading edge. Internal skin separation by rupture below the protective strip is seen.



MRB upper surface 3.0 - 3.9 m away from the "zero line", seen towards the leading edge. Internal skin by rupture (left) as well as strip bonding separation (right) are observed.

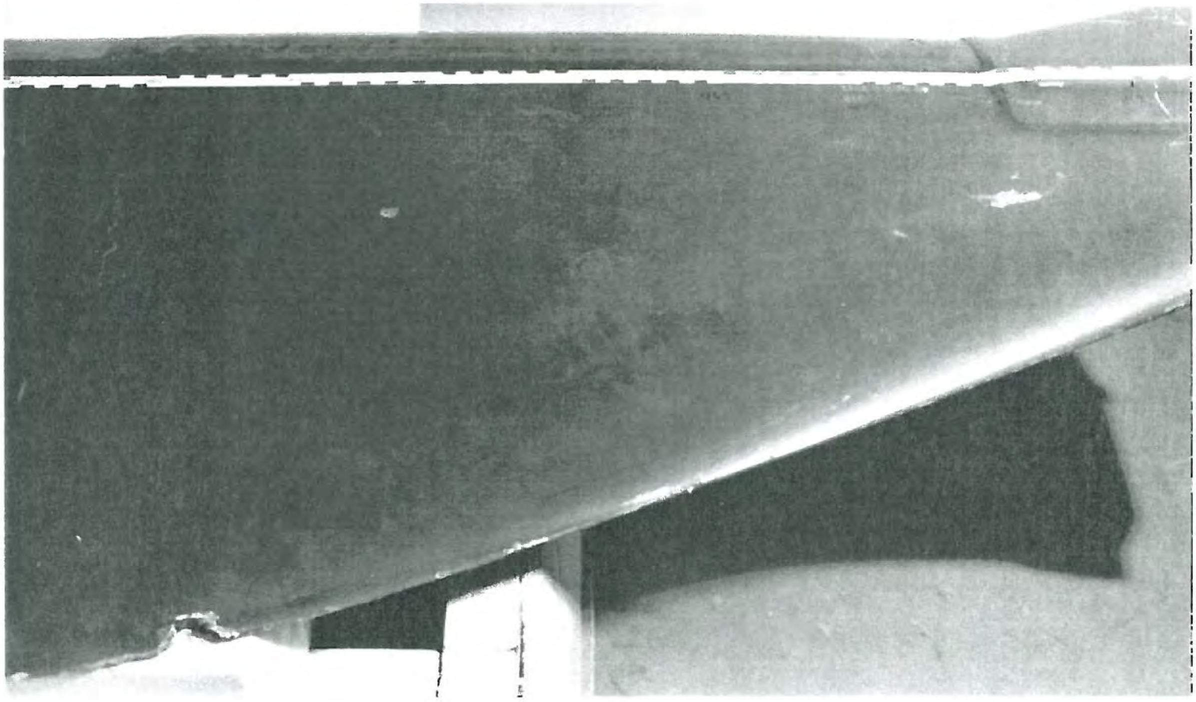


MRB upper surface 3.6 - 4.4. m away from the "zero line", seen towards the leading edge. Separation between the protective strip and the underlying blade structure is noted.



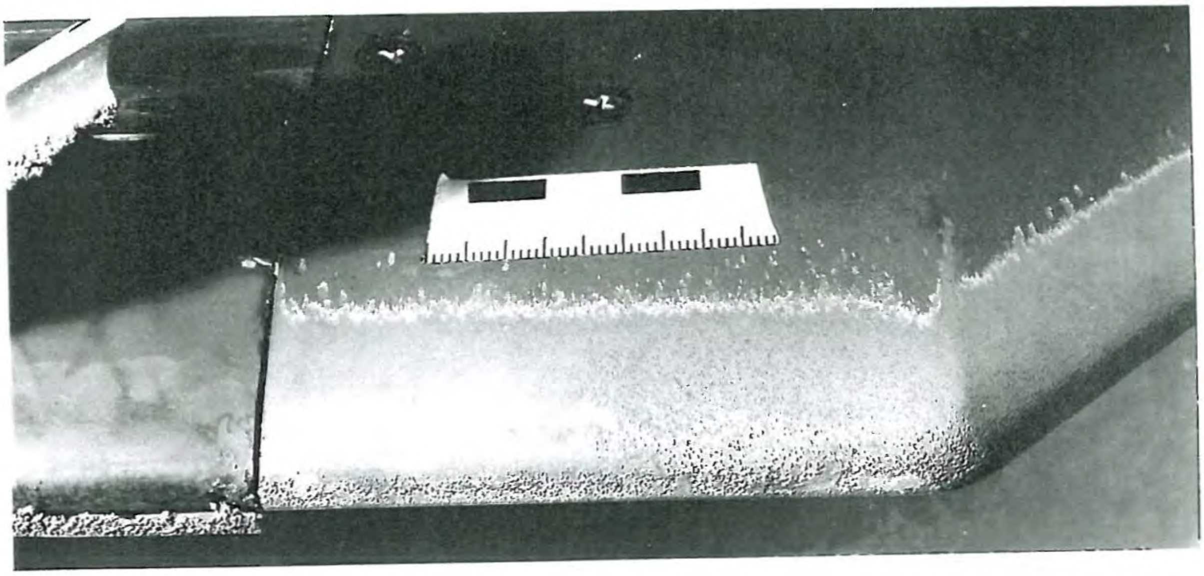
MRB upper surface 4.2. - 5.0 m away from the "zero line", seen towards the leading edge. Separation between the protective strip and the underlying blade surface is seen.

MRB upper surface 4.8. - 5.6. m away from the "zero line", seen towards the leading edge. Protective strip separation is noted locally.

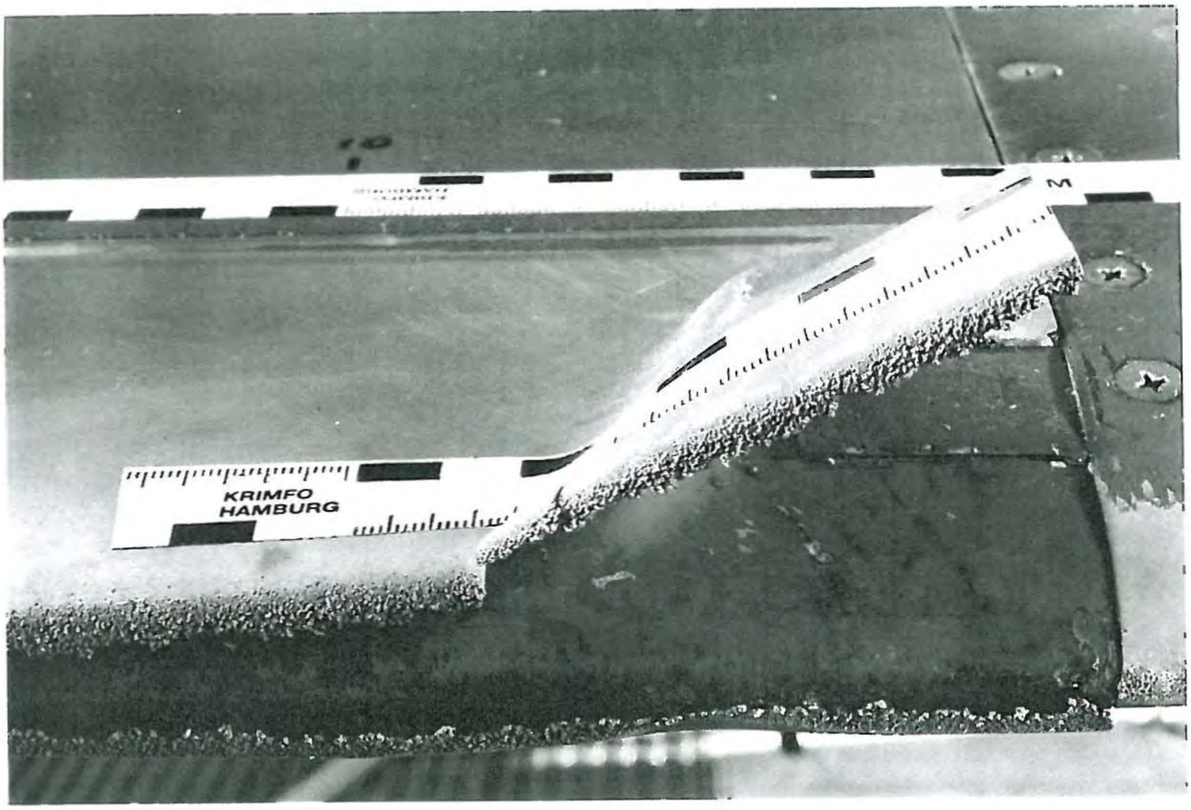


MRB upper surface 5.4. - 6.2. m from the "zero line", seen towards the leading edge.

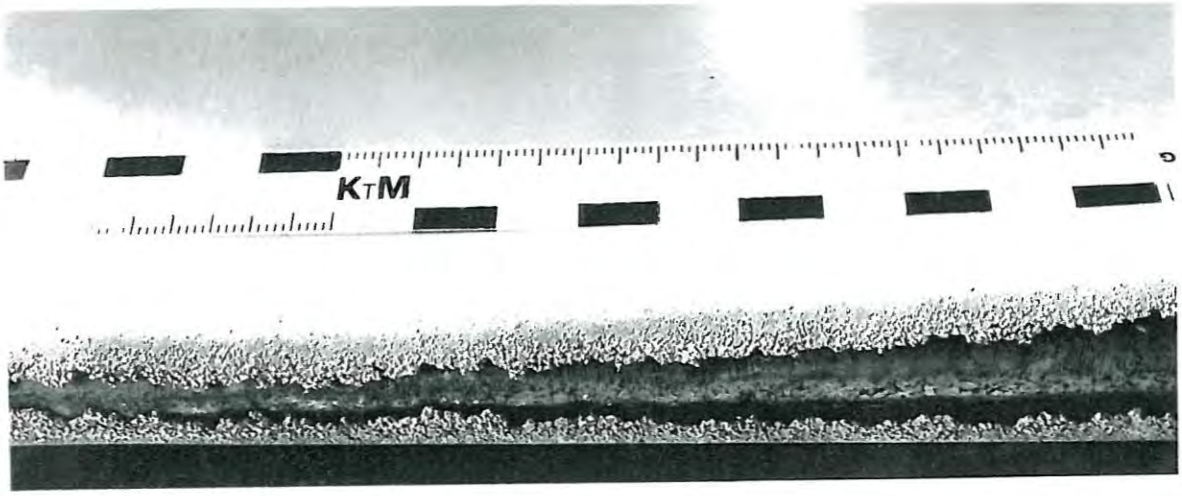
FIGUR 15 A/B



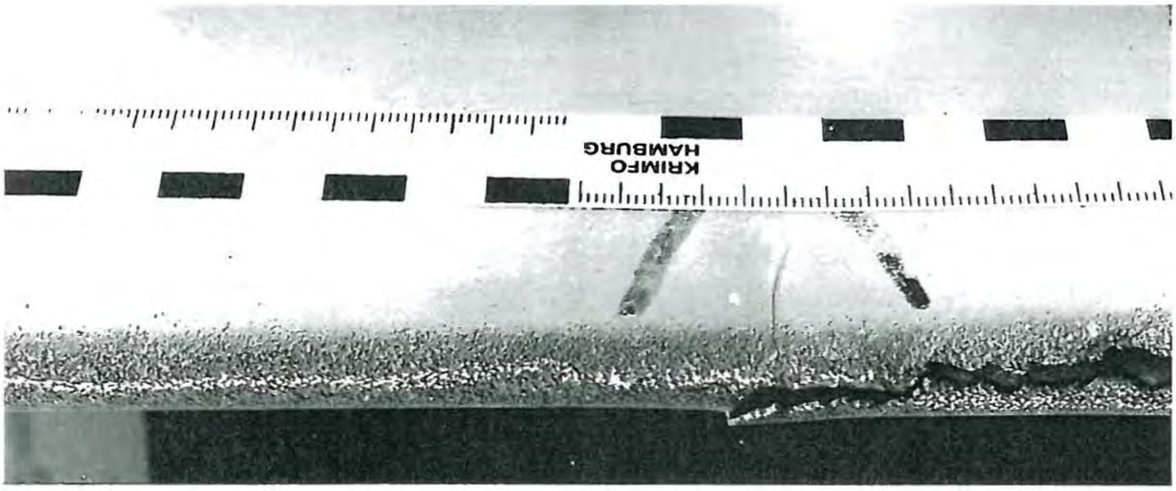
Detail registration photo showing the surface wear suffered by the leading edge and the adjacent upper surface of the tip cap.



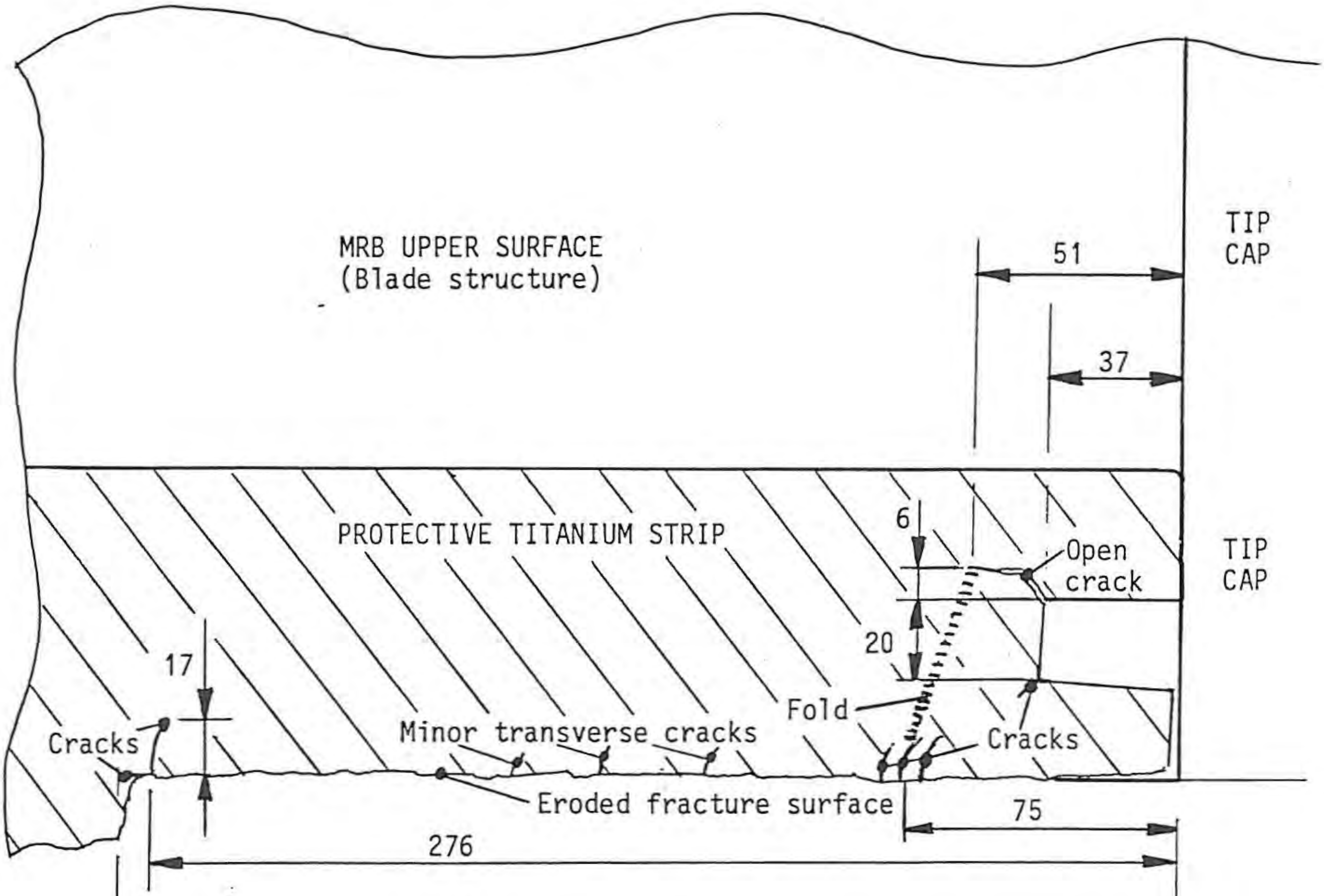
Detail registration photo showing the fracture deformation and surface wear suffered by the leading edge and the adjacent upper surface of the outer 0,12 m of the protective Ti-strip.



Detail registration photo showing the fracture deformation and surface wear suffered by the leading edge and the adjacent upper surface of the protective Ti-strip, 0,10 - 0,24 m away from the "zero line".



Detail registration photo showing the fracture deformation and surface wear suffered by the leading edge and the adjacent upper surface of the protective Ti-strip, 0,23 - 0,38 m away from the "zero line".



Sketch illustrating the pattern of folds, cracks and fractures seen at the outer end of the protective Ti-strip of the MRB S/N 617. All dimensions given in millimetres (mm).

1.16.2.4 The leading edge strip was eroded on the leading edge along large parts of the blade's length. The sites of erosion damage increased markedly towards the blade tip and the leading edge strip was perforated in places along the outer 285 mm.

1.16.2.5 A dent in the underside of the leading edge strip, 36-58 mm from the zero line was examined in detail in an Optical Stereo Microscope (OSM). During these examinations, scratches were discovered in the centre of the dent, having an angle of approx. 20° in relation to the longitudinal axis of the blade. The scratches were shiny and looked as if they were new. This dent is not apparent on the underwater photograph of the area which was taken prior to the start of dismantling and raising (refer to the differences in Figures 7A and 7B).

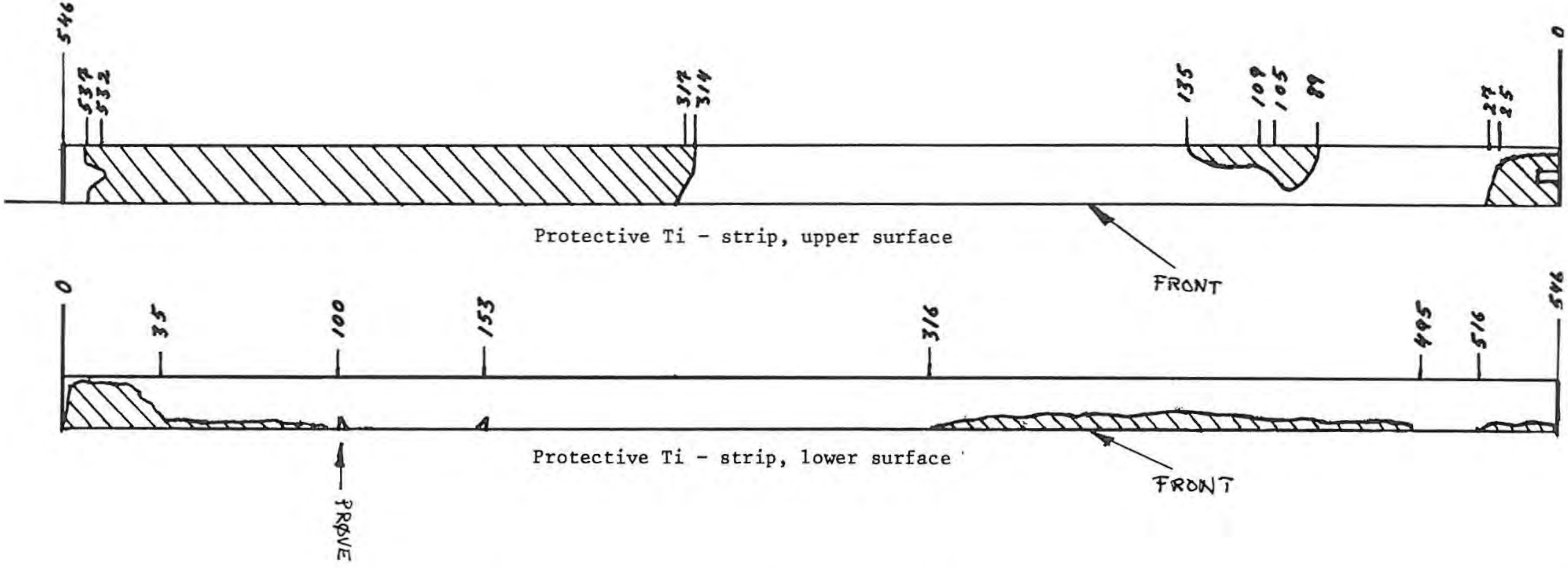
1.16.3 Charting the status of the vulcanisation between the leading edge strip and the de-icer element on main rotor blade S/N 617 after the accident

1.16.3.1 In an attempt to chart any delamination between the leading edge strip and the de-icer element, the main rotor blade was checked in accordance with the Eurocopter Maintenance Manual, MET 62.10.00.603 'Bonding checks by tapping' (see Appendix 2). The results are marked on Figure 18. Parts of this result were verified by the leading edge strip being removed from the blade in places (see Figures 19A-21A). During the work of removing the leading edge strip, it was ascertained that the strip's 'bond' with the base layer was either very good or was completely missing. No poor 'bonding' was found. In report no. 96-3548, drawn up by DNV, this is discussed as follows:

> "The general impression related to the aspect of bonding is that there is no stage between 'bonding' and 'no bonding'. Therefore, the expressions 'good bonding' or 'poor bonding' are irrelevant. Where bonding exists, a considerable force is required to separate the Ti strip from the underlying primers and blade structure. Within the debonded areas no force at all is needed for the corresponding separation."

1.16.3.2 The surface of the base layer which became visible after the leading edge strip was removed was grey in colour, identical to the colour of 'Primer I' (cf. 1.16.1.2). Figures 7B, 20 and 21A show that, in places, the surface had brown stripes which are reminiscent of 'brush strokes'. In places, the difference between the leading edge strip's bonding with the base layer and areas with no bonding follows the pattern of the 'brush strokes'. In an attempt to find the cause of these brown stripes, samples were investigated by DNV in the Scanning Electron Microscope (SEM), and Energy Dispersive Spectrometric (EDS) analyses were undertaken without revealing any significant differences between the 'brown' and 'grey' surfaces.

1.16.3.3 A sample was also excised, 27 mm into the leading edge of the blade, 100 cm from the zero line. This sample was taken in an area where the tapping test indicated a good bond between the leading edge strip and the base layer (no delamination).

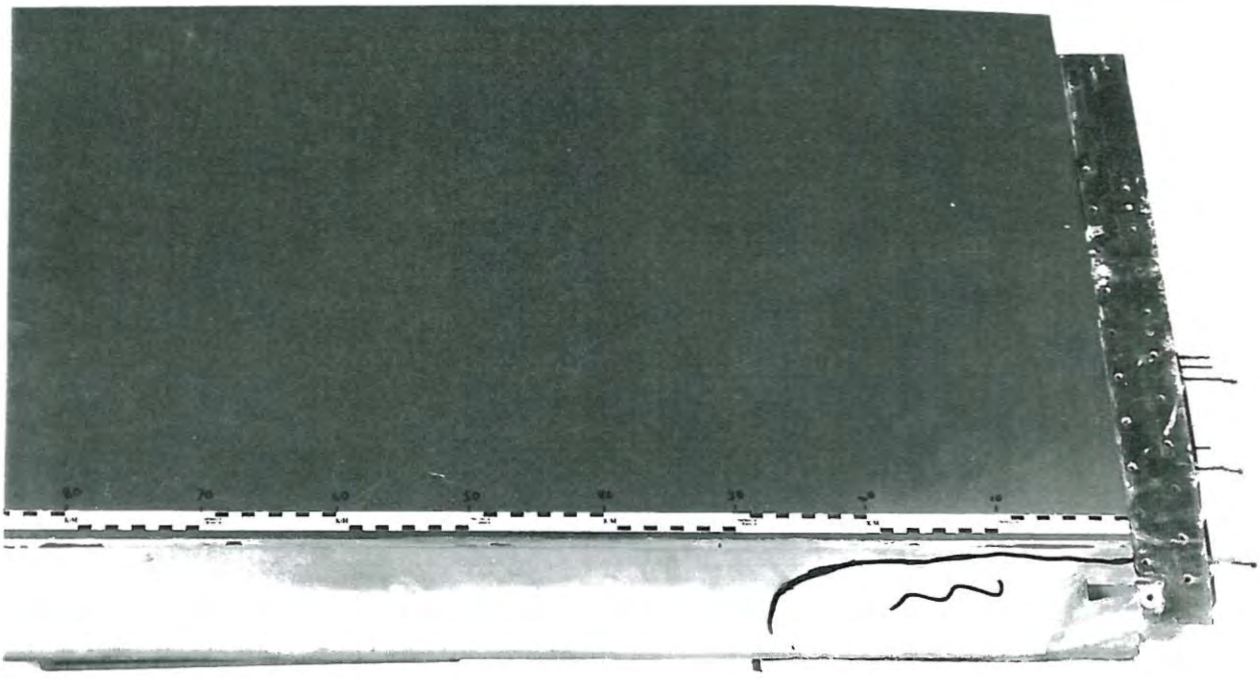


Protective Ti - strip, upper surface

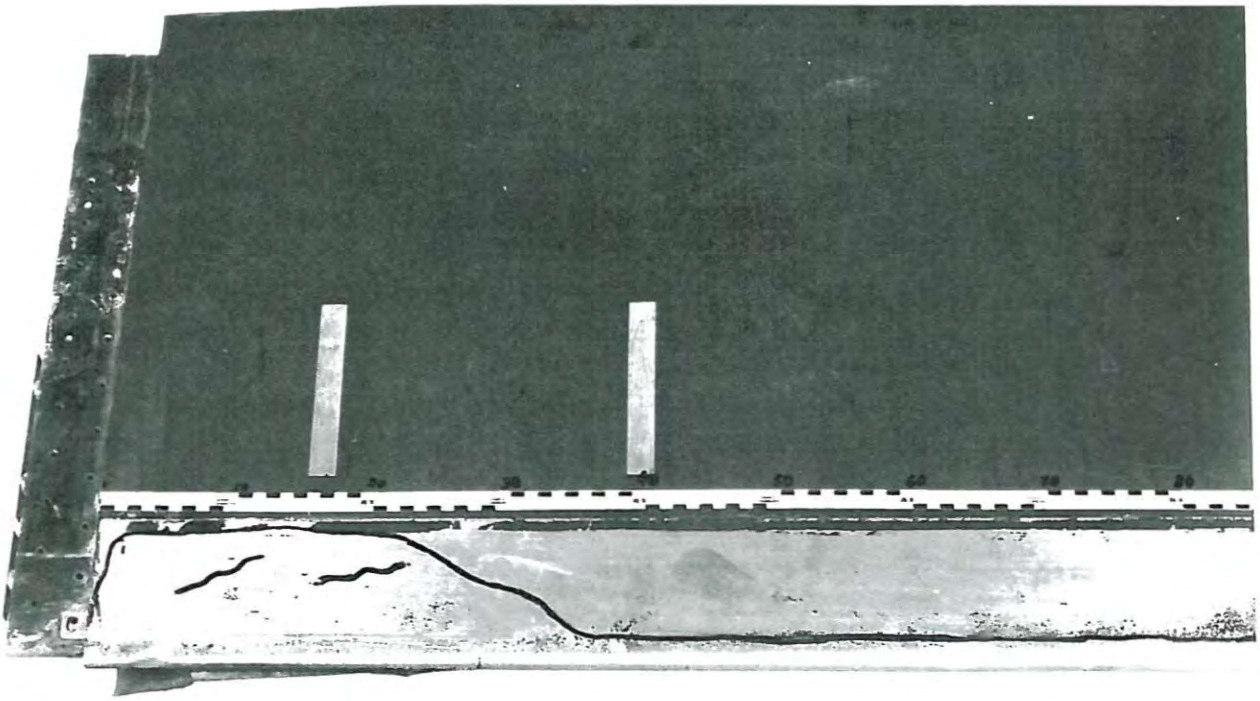
Protective Ti - strip, lower surface

Sketch showing the pattern of bonding, based on the accoustic tapping method. The shaded areas represent areas where lack of bonding was indicated. All locations given in centimetres (cm) away from the "zero line".

FIGUR 18



General view of the upper surface of the outer section of the failed MRB, illustrating the borderline of bonding for the protective Ti-strip at the outer end. The borderline determination is based on acoustic tapping.



General view of the lower surface of the outer section of the failed MRB, illustrating the borderline of the bonding for the protective Ti-strip at the outer end. The borderline determination is based in acoustic tapping.

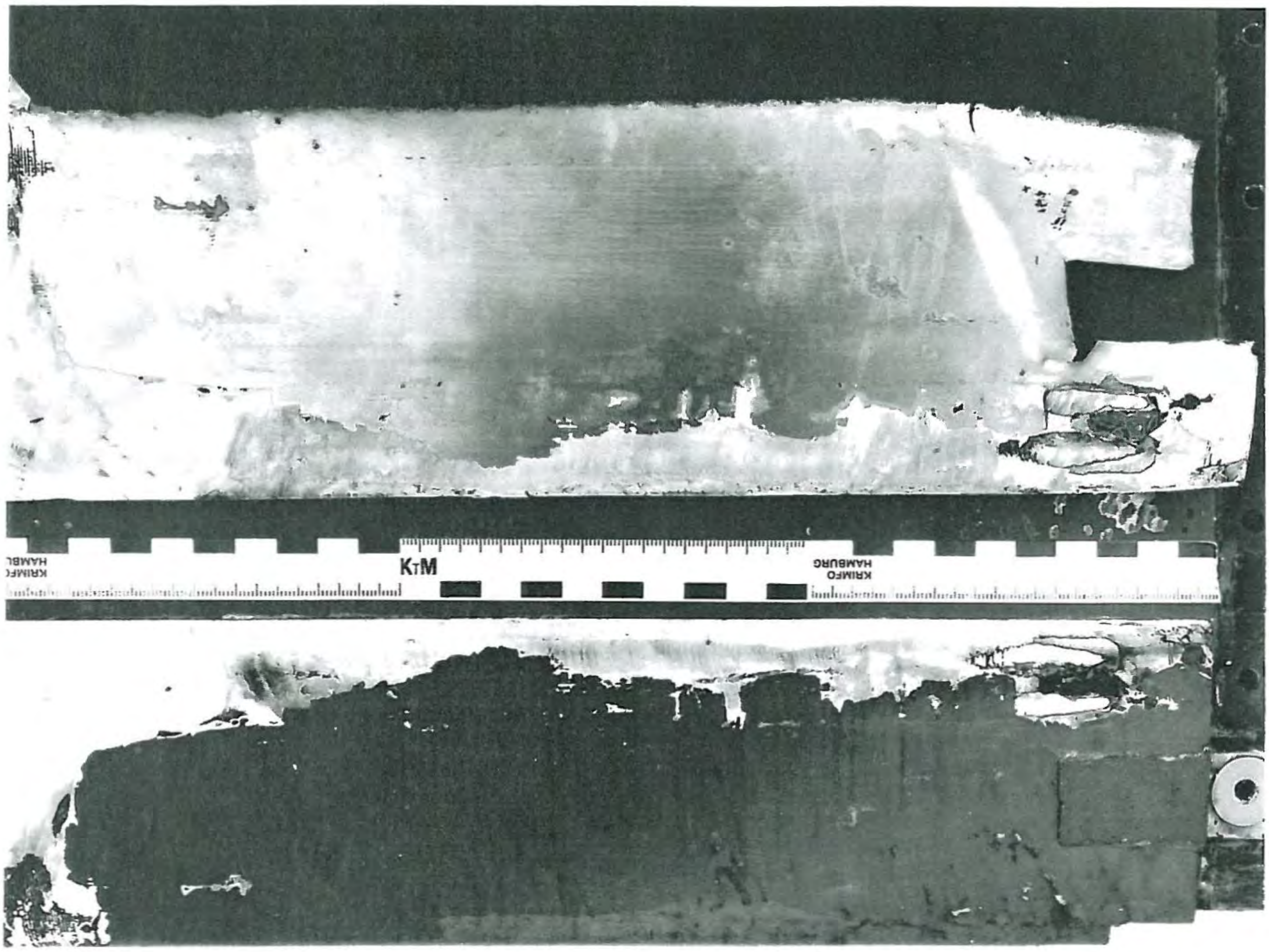


Photo showing the bonding surface of the protective Ti-strip (top) and the mating bonding surface of the blade structure (below). The geometry of the adhesive bonding for the upper blade surface should be compared with the borderline photo shown in Fig. 19A.

FIGUR 21 A/B

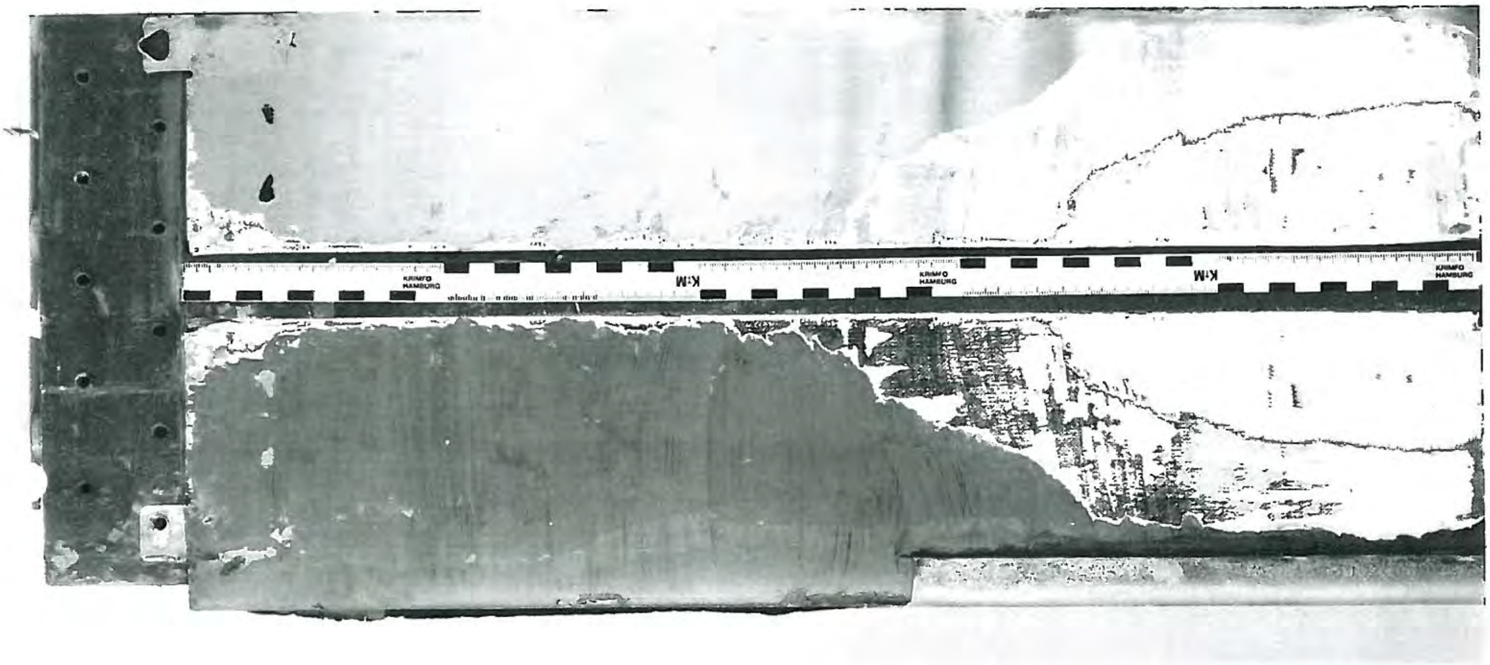
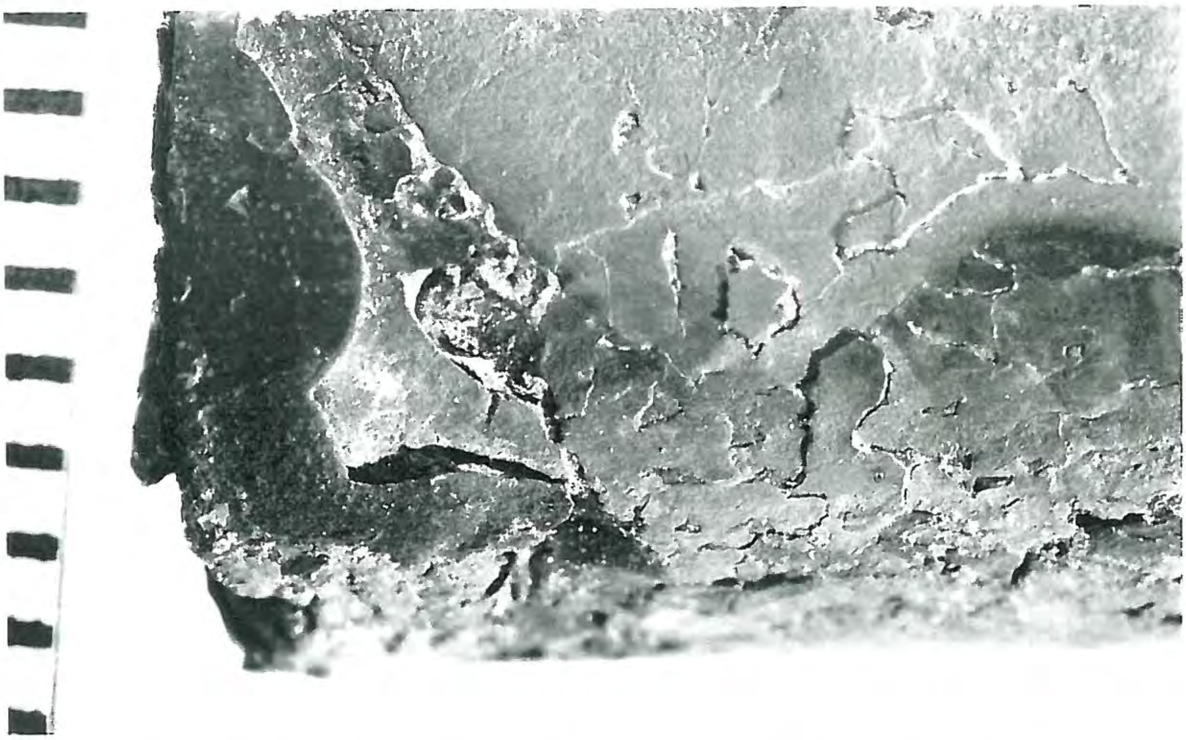


Photo showing the bonding surface of the protective Ti-strip (top) and the mating bonding surface of the blade structure (below). The geometry of the adhesive bonding for the lower blade surface should be compared with the borderline photo shown in Fig. 19B.



Close-up photo showing surface details of the blade structure of the leading edge.

After the sample, which represented a section into the blade, was excised, the blade structure and the de-icer element came loose from the leading edge strip. Impressions from the leading edge strip in the primer/neoprene, however, indicated that the materials did have good contact even within the smallest radius on the leading edge strip.

1.16.3.4 Figure 21B shows a close-up picture of the surface at the zero line after the leading edge strip was removed. The dark area on the left of the picture represents an elevation of the surface which led to reduced contact between the leading edge strip and the base layer. These may be seen as irregularities on the left of the picture.

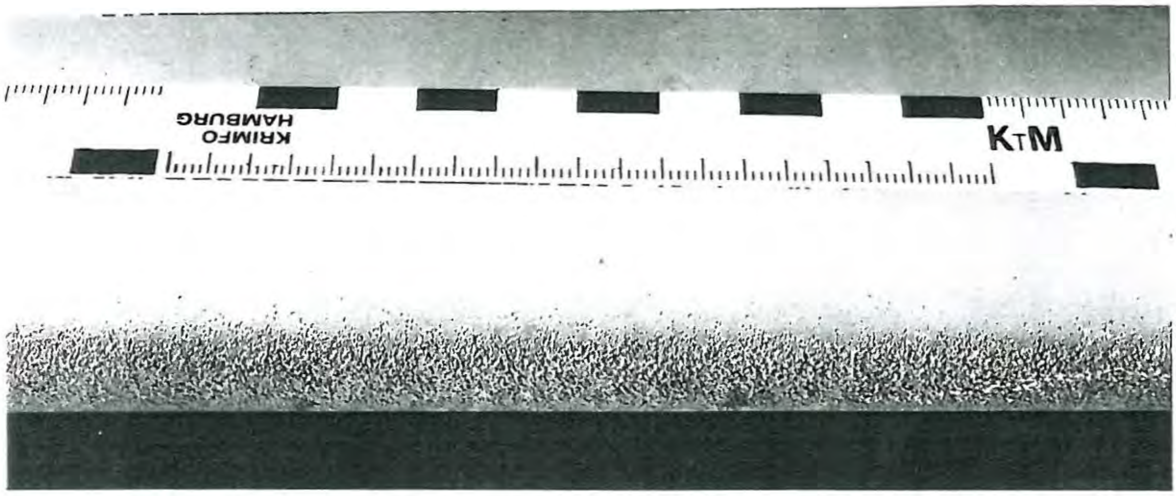
1.16.3.5 In addition, it was not possible to find any variations or differences in the nature of the surface in the areas where there was no bonding. This indicates that the delamination had occurred as a result of the same fault mechanism (s).

1.16.4 Erosion of the leading edge strip of main rotor blade S/N 617

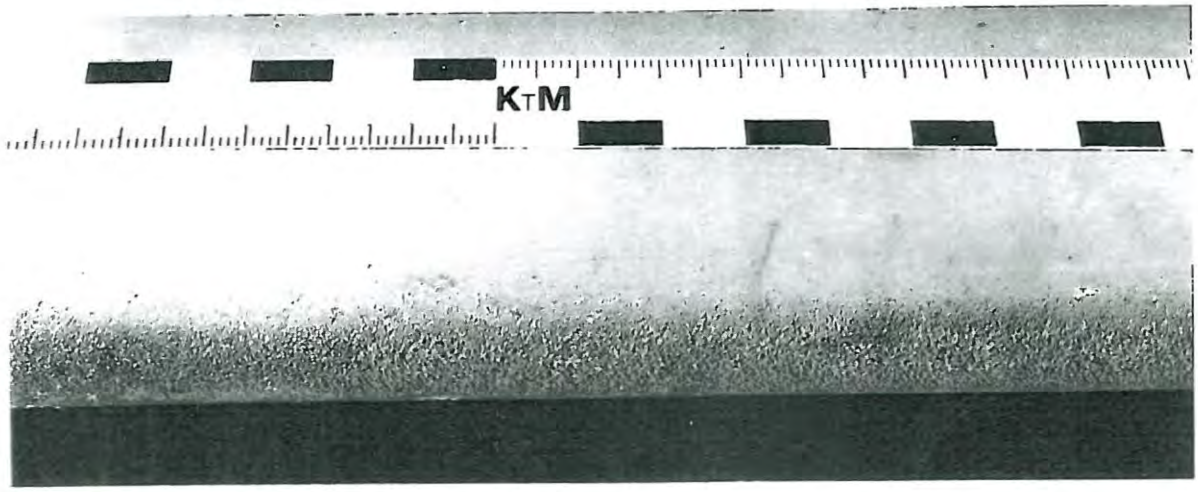
1.16.4.1 As mentioned in the introduction, the front of the leading edge strip was eroded to an increasing degree towards the blade tip (see Figures 15B, 16A/B, 22A/B, 23A/B and 24). This erosion partially holed the strip (see Figures 25B, 26A/B), and removed parts of it (see Figures 27A/B, 28A/B, 29A/B and 30). To discover, using the best possible method, the amount of material which was missing from the strip, the two halves of the crack were photographed by DNV and then photographically reconstructed. The result was drawn out on paper (see Figure 31). Black fields on the sketch represent a lack of materials, and white fields represent areas in which deformation of the strip has led to the two halves overlapping. It is important to note that the black areas represent the maximum area which might have eroded, and not necessarily the situation before the last flight took off. Since fragments of the Ti material could be easily removed from the leading edge strip afterwards, it is probable that the last flight, the tearing up of the crack and the sinking/salvaging of the helicopter may have affected the total quantity of materials missing according to the sketch.

1.16.4.2 Figure 32A clearly shows that the material under the leading edge strip (the de-icer element) has small 'pin holes' inside the surface of the neoprene. An examination undertaken by DNV showed that these 'holes' could penetrate 1-2 mm under the surface, but that, with the exception of a brown pigment, they were empty. According to DNV, this provides a strong indication that the most damaging erosion while the main rotor blade was being used was caused by water droplets (liquid impingement erosion). This is described as "progressive loss of original material from a solid surface due to continued exposure to impacts by liquid drops or jets" (cf. 'Standard Terminology Relating to Wear and Erosion', G 40, Annual Book of ASTM Standards and 'Liquid Impingement Erosion', Frank J. Heyman, ASM Handbook, Volume 18).

FIGUR 22 A/B



Detail registration photo showing the surface wear suffered by the leading edge and the adjacent upper surface of the protective Ti-strip, 0,38 - 0,52 m away from the "zero line".



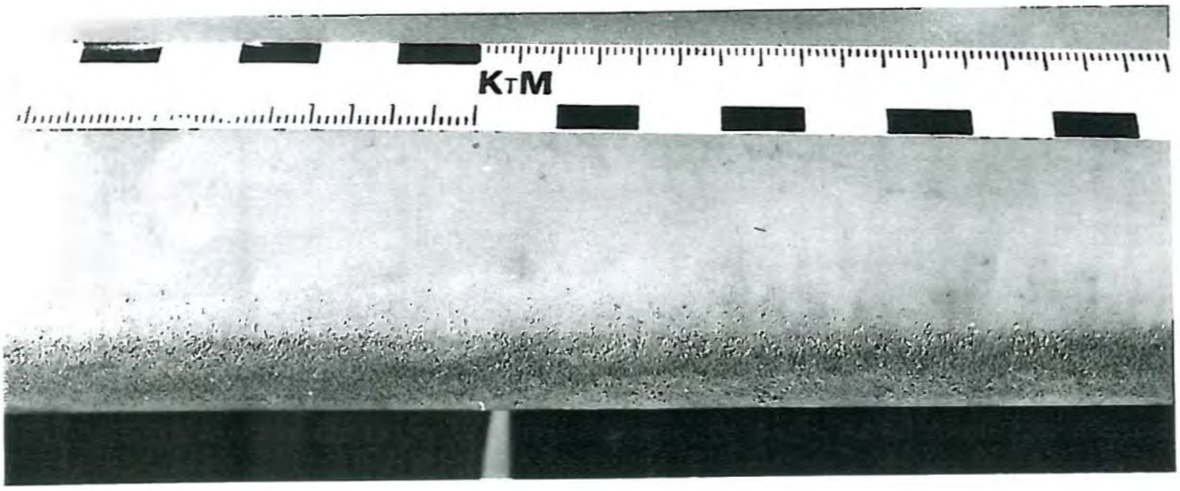
Detail registration photo showing the surface wear suffered by the leading edge and the adjacent upper surface of the protective Ti-strip, 0,53 - 0,66 m away from the "zero line".

FIGUR 23 A/B

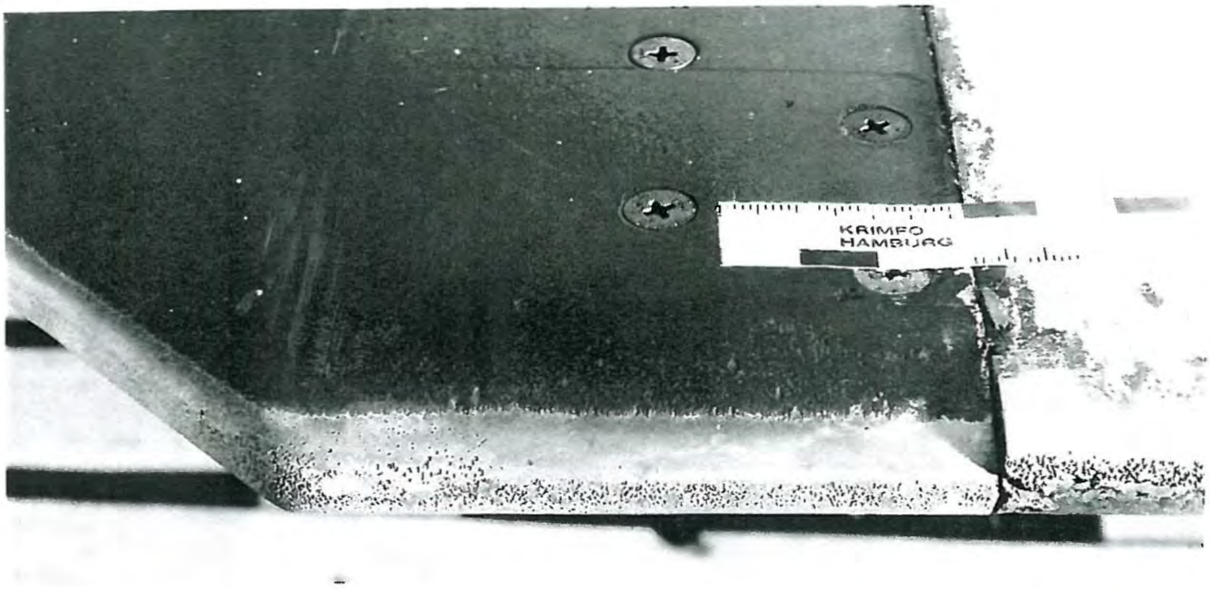
Detail registration photo showing the surface wear suffered by the leading edge and the adjacent upper surface of the protective Ti-strip, 0,66 - 0,79 m away from the "zero line".

Detail registration photo showing the surface wear suffered by the leading edge and the adjacent upper surface of the protective Ti-strip, 0,79 - 0,92 m away from the "zero line".

FIGUR 24 A/B



Detail registration photo showing the surface wear suffered by the leading edge and the adjacent upper surface of the protective Ti-strip, 0,92 - 1,05 m away from the "zero line".



Detail registration photo showing the surface wear suffered by the leading edge and the adjacent lower surface of the tip cap.

Detail photo from interior corner of modification cut-out. The crack in this corner of the protective Ti-strip is found somewhat open due to material deformation.

Photo illustrating the fracture profile in the outer portion of the protective Ti-strip. The interior (bonding) surface 0 - 0,1 m from the "zero line" (left) is seen.

FIGUR 26 A/B

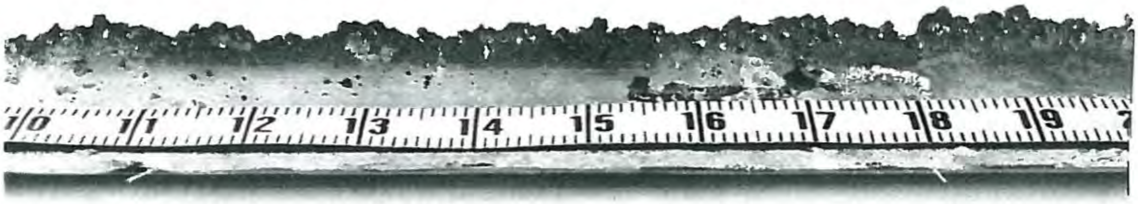
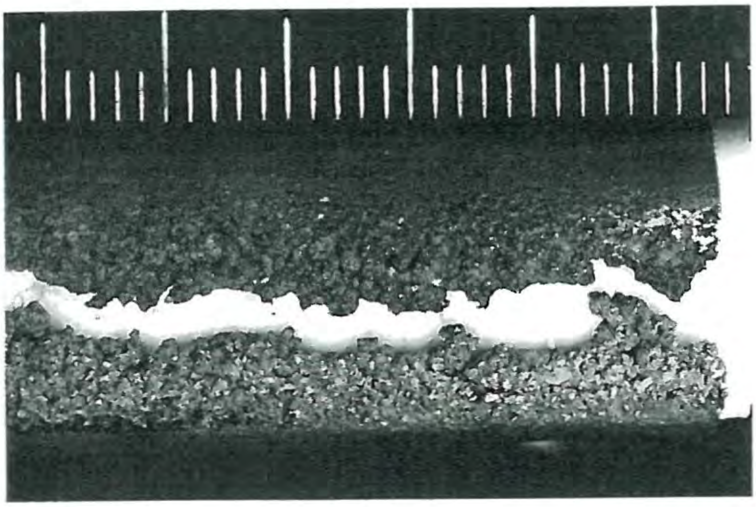
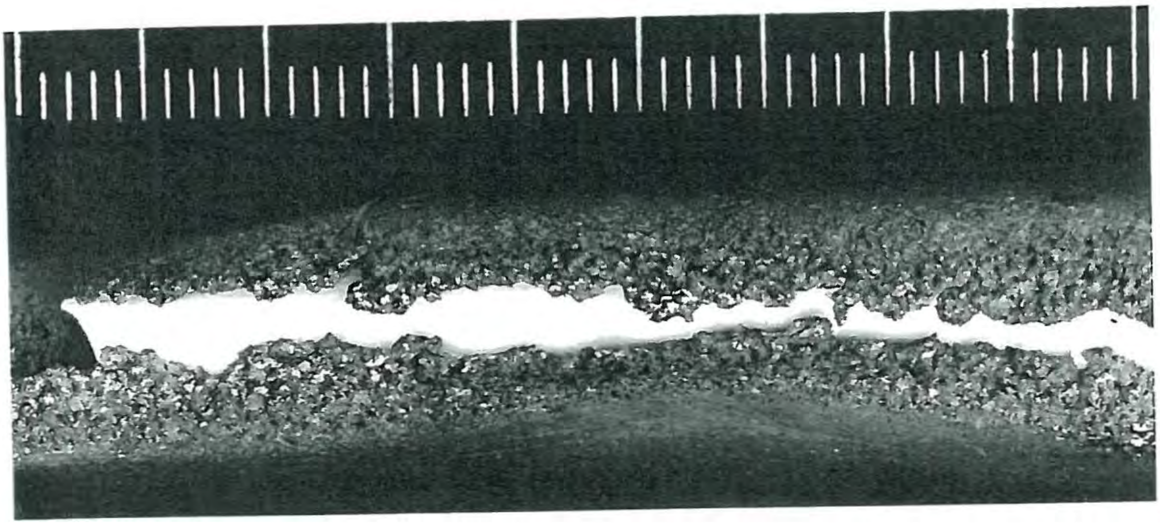


Photo illustrating the fracture profile in the outer portion of the protective Ti-strip. The interior (bonding) surface 0.1 - 0.19 m away from the "zero line" is seen.

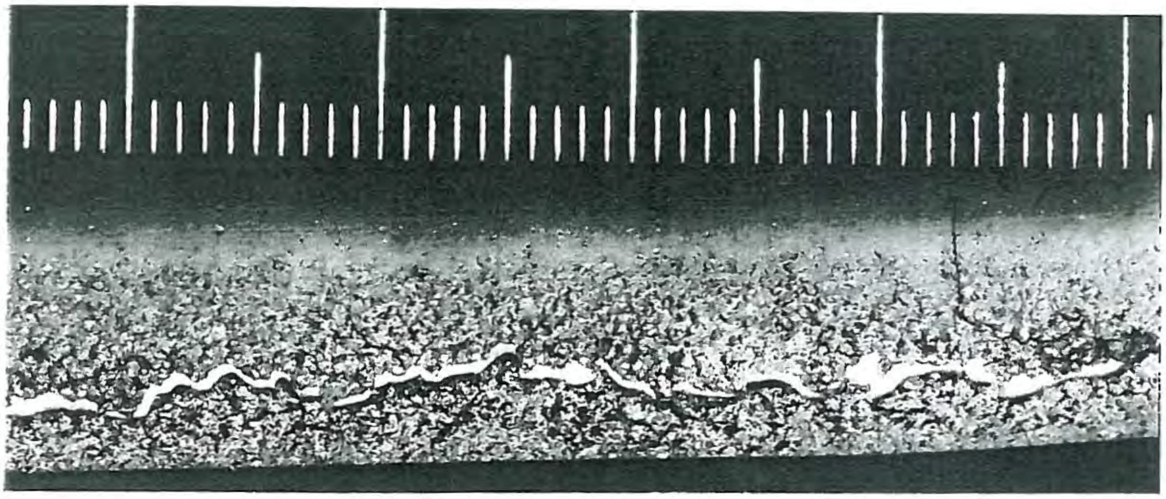
Photo illustrating the fracture profile in the outer portion of the protective Ti-strip. The interior (bonding) surface 0.19 - 0285 m away from the "zero line" is seen.



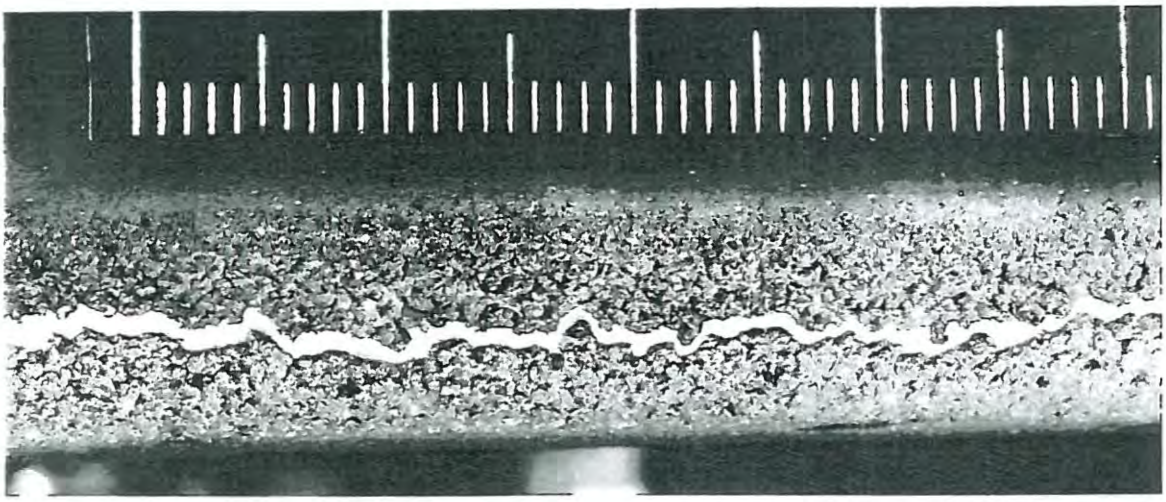
Detail photo showing the fracture profile and the leading edge wear of the outer cut section of the protective Ti-strip. The "zero line" is located at the right hand side of this photo.



Detail photo showing the fracture profile and the leading edge wear of the second cut section from the outer end of the protective Ti-strip.

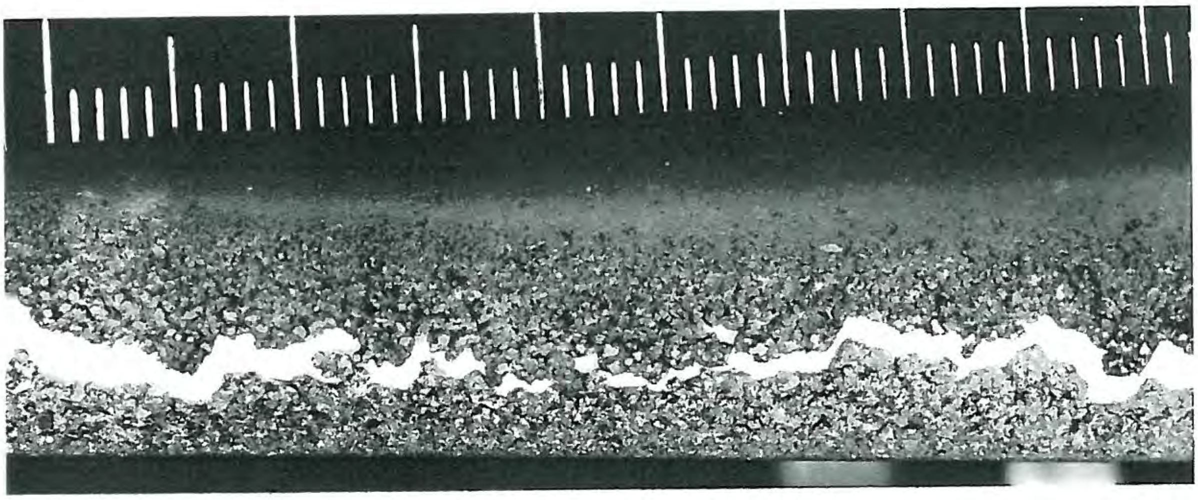


Detail photo showing the fracture profile and the leading edge wear of the third cut section from the outer end of the protective Ti-strip.

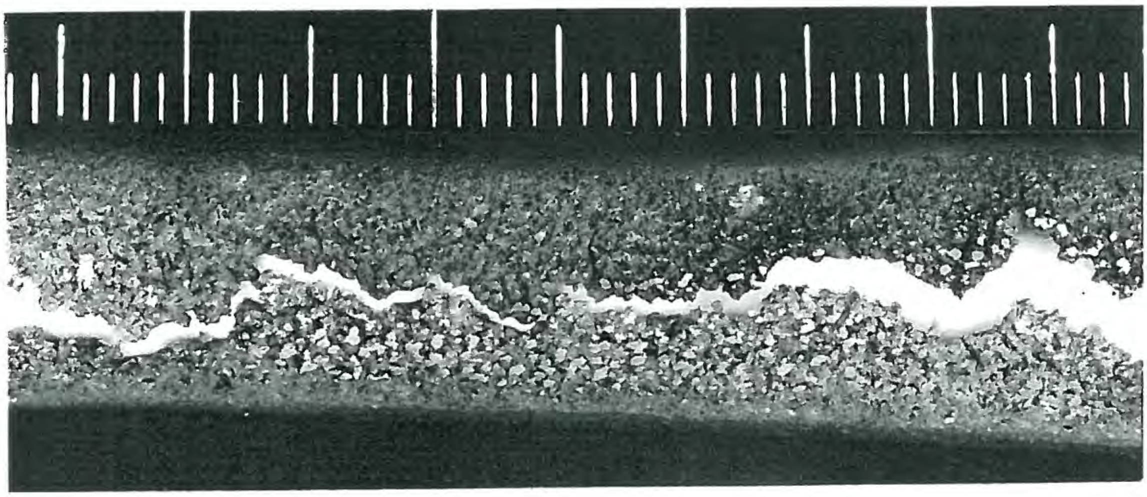


Detail photo showing the fracture profile and the leading edge wear of the fourth cut section from the outer portion of the protective Ti-strip.

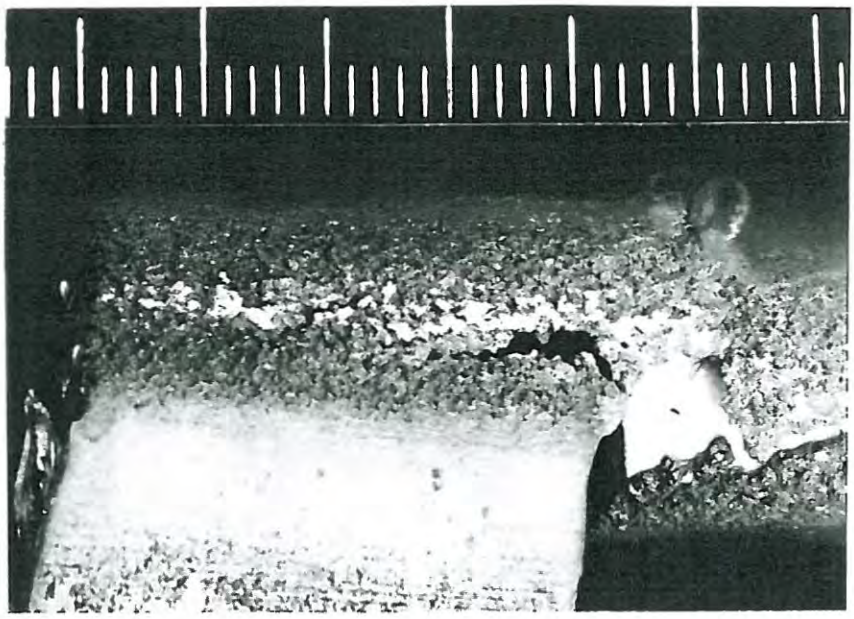
FIGUR 29 A/B



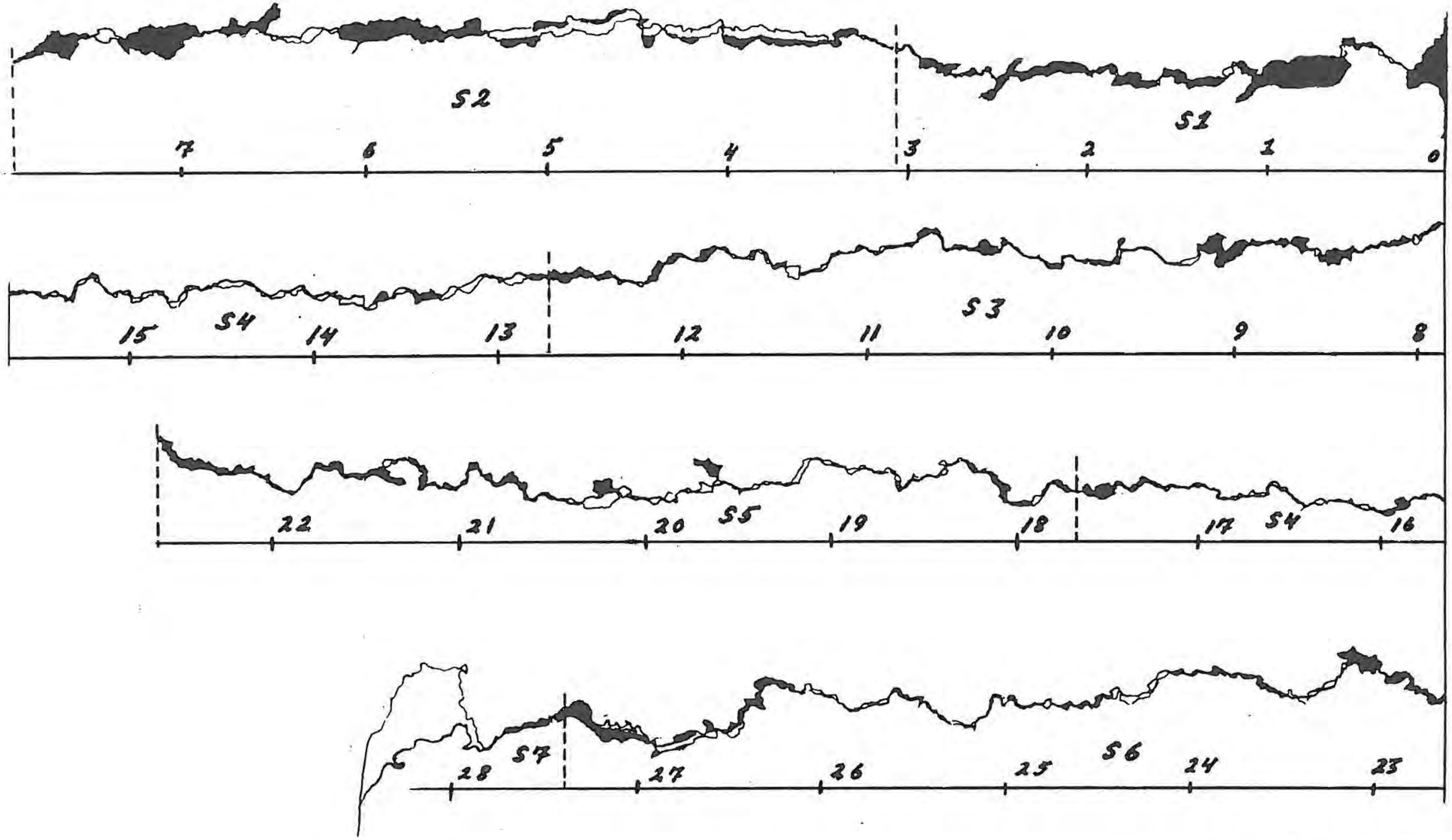
Detail photo showing the fracture profile and the leading edge wear of the fifth cut section from the outer portion of the protective Ti-strip.



Detail photo showing the fracture profile and the leading edge wear of the sixth cut section from the outer portion of the protective Ti-strip.

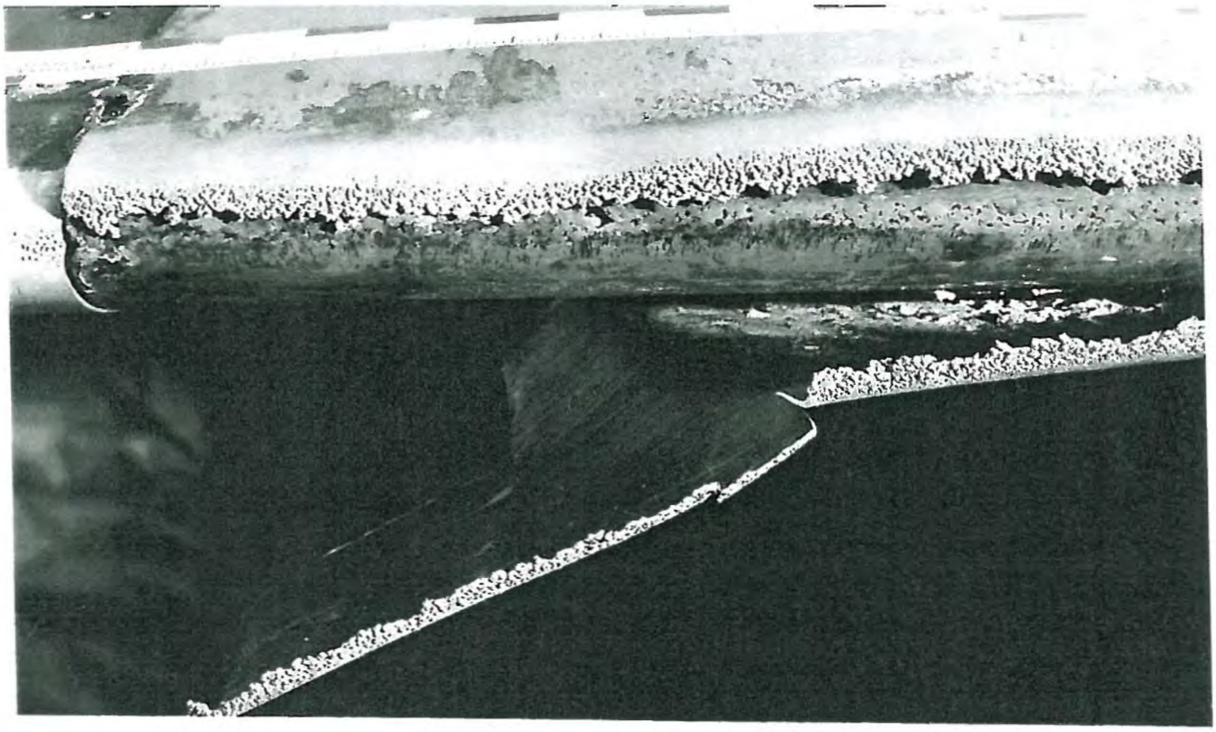


Detail photo showing the fracture profile and the leading edge wear of the seventh cut section from the outer portion of the protective Ti-Strip (inner end of the leading edge fracture).

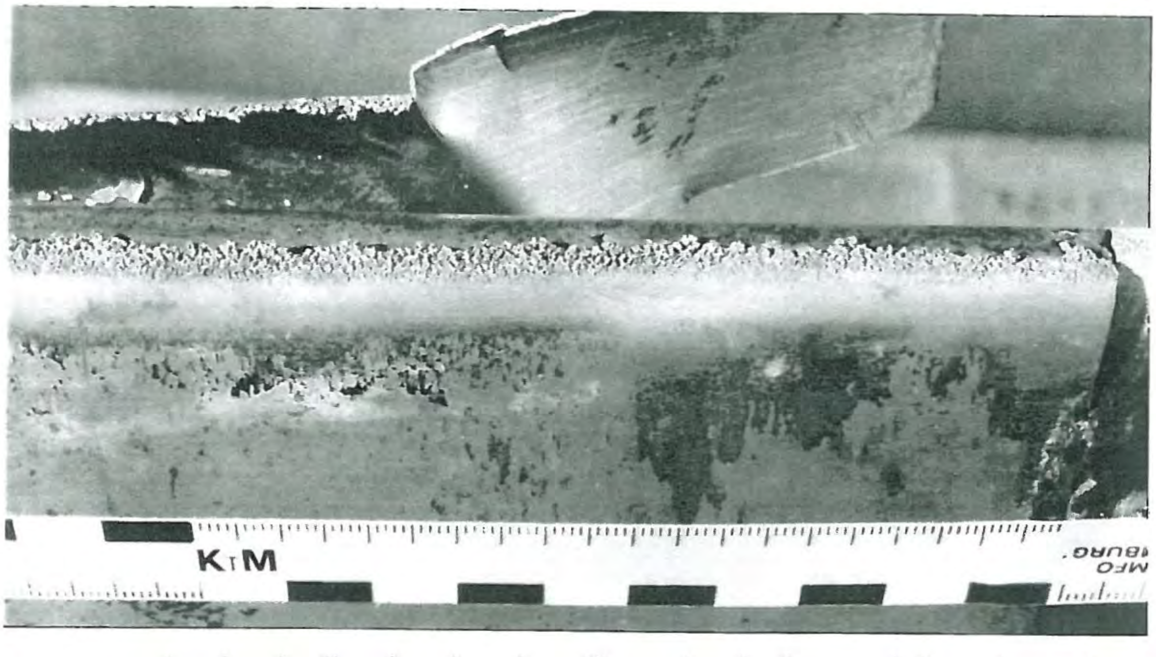


Sketch illustrating the profile of the eroded fracture surfaces at the leading edge, elements S1 - S7, respectively. The scale 0 - 28.5 represents the location in centimetres from the "zero line". The dark areas represent eroded surface material missing after the accident.

FIGUR 31



Detail registration photo showing the fracture deformation and surface wear suffered by the leading edge and the adjacent lower surface of the outer 0,12 m of the protective Ti-strip.



Another detail registration photo illustrating the fracture deformation and surface wear suffered by the leading edge and the adjacent lower surface of the outer 0,12 m of the protective Ti-strip.

1.16.4.3 Figure 33A/B shows pollution found in the surface of the leading edge strip. EDS analyses of this and other similar 'objects' showed that these were principally sand particles. These pollutants were discovered in small quantities, and DNV concludes by stating that this also indicates liquid impingement erosion as the principal reason for the erosion along the leading edge strip.

1.16.4.4 It has been proven that major forces can occur with this type of erosion. It is assumed that, at normal rotor and running speeds, one droplet can expose the metal strip to forces 275 MPa. This is equal to the limit of tolerance for Titanium T-40, which is used in this instance.

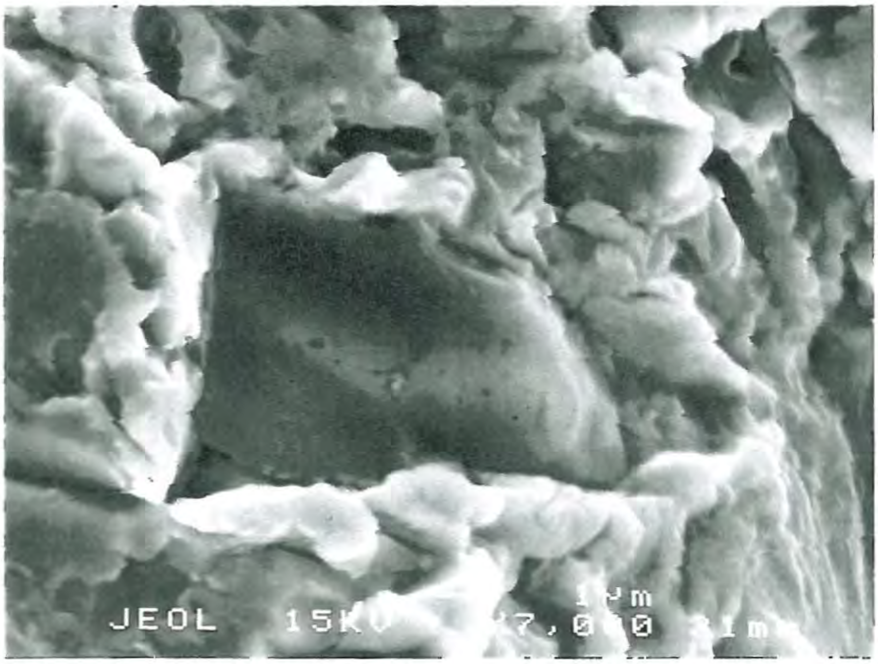
1.16.5 Examination of the pattern of cracks on main rotor blade S/N 617

1.16.5.1 A piece of the leading edge strip, 285 mm long, containing one half of the main crack (the lower side) was cut away and examined more closely by DNV. To fit the pieces into the SEM, the piece was cut into 7 sections (S1 - S7) where S1 represents a segment which was 0-31 mm from the zero line. Figure 34 represents the erosion of the leading edge strip along the edge of the crack. Figure 35B illustrates part of the crack surface at S1. The picture shows that the leading edge strip was perforated by erosion in places. A framed section of the picture is illustrated at x350 magnification in Figure 36A. This picture shows the microstructure in a transition zone between an even surface and a more uneven surface against the vulcanised surface (at the top of the picture). A further magnification to x1200, in Figure 36B, shows that the lower part contains a microstructure with parallel lines (striations) characteristic of a fatigue fracture. The upper part contains a microstructure equivalent to a overload fracture. This general picture of the character of the crack was also confirmed in sections S2 - S7, but such that erosion has contributed to a gradually smaller portion of the crack's shape at S7 compared with S1. In its report, DNV stated:

> "This erosion damage - together with a dynamic load situation - has contributed to the initiation and propagation of fatigue cracks from surface grooves/cavities. A total length of 28.5 cm at the outer end of the Ti strip has suffered leading edge fracture as a consequence of erosion and fatigue."

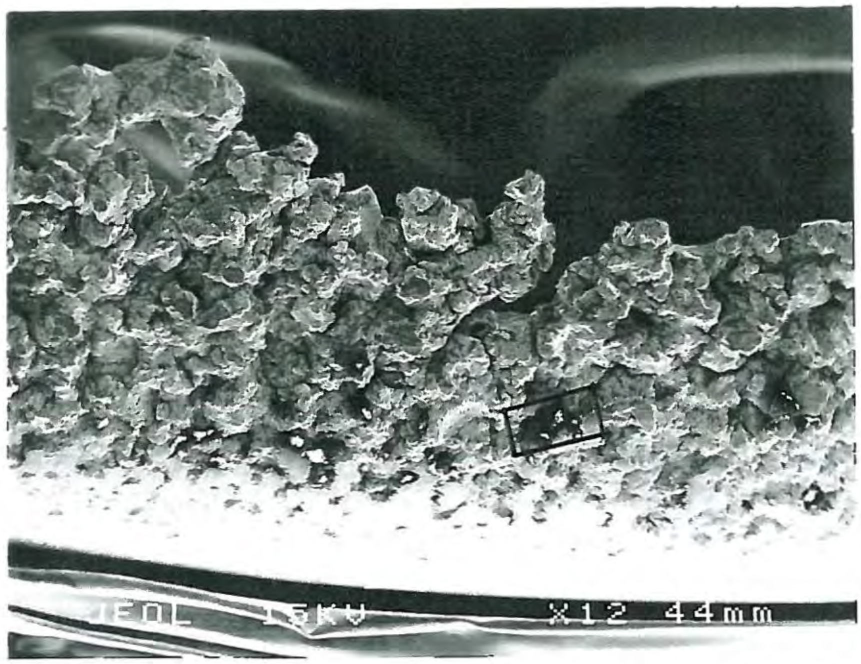
1.16.5.2 As previously discussed in section 1.16.2.3, the main cracks had 8 transverse cracks linked to the main crack. Two of these cracks from section S2 were examined in more detail in the SEM. One of the cracks is illustrated in Figure 37A. This crack proved to have been caused by a fatigue fracture both in its starting area (see Figure 37B) and at the crack toe (extension area) (see Figure 38A). This is further confirmed in detail on the picture in Figures 38B and 39A. The crack's length was measured at 9.8 mm. The total number of load cycles was estimated at approx. 22,790, based on four counts of parallel lines (striations) in the crack (two at the beginning and two in the extension area). Based on the fact that a load cycle comprises one rotation of the helicopter's main rotor, it is equivalent to a flight of

General micropattern appearance of the fracture surface from the section S1. A foreign matter particle is seen embedded in the Ti surface (arrowed). SEM-photo, magnification x 1000.



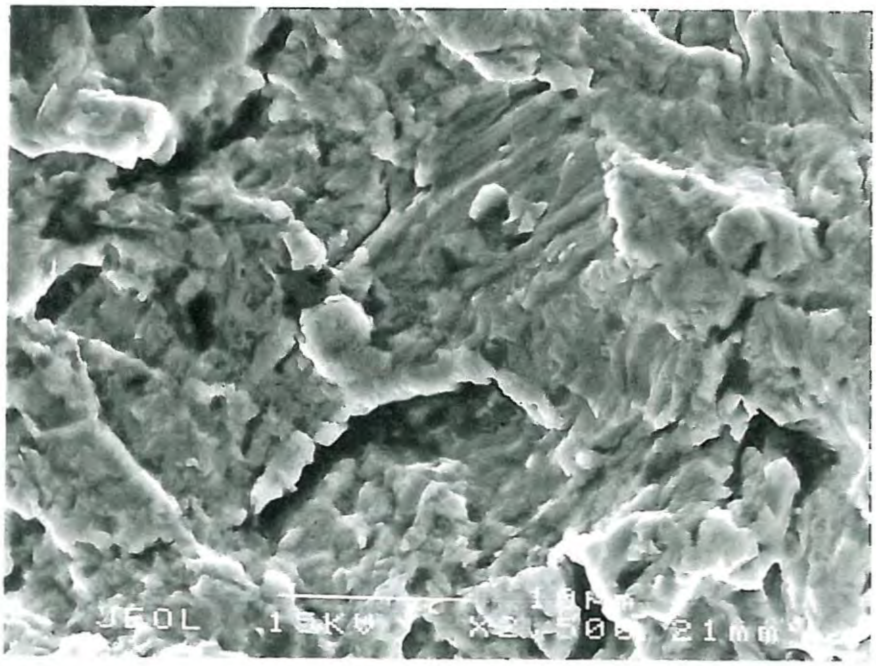
SEM close-up photo of the particle arrowed in Fig. 33A. By the EDS analysis carried out, the particle in question was found to be a sand particle. Magnification x 7000.

FIGUR 34

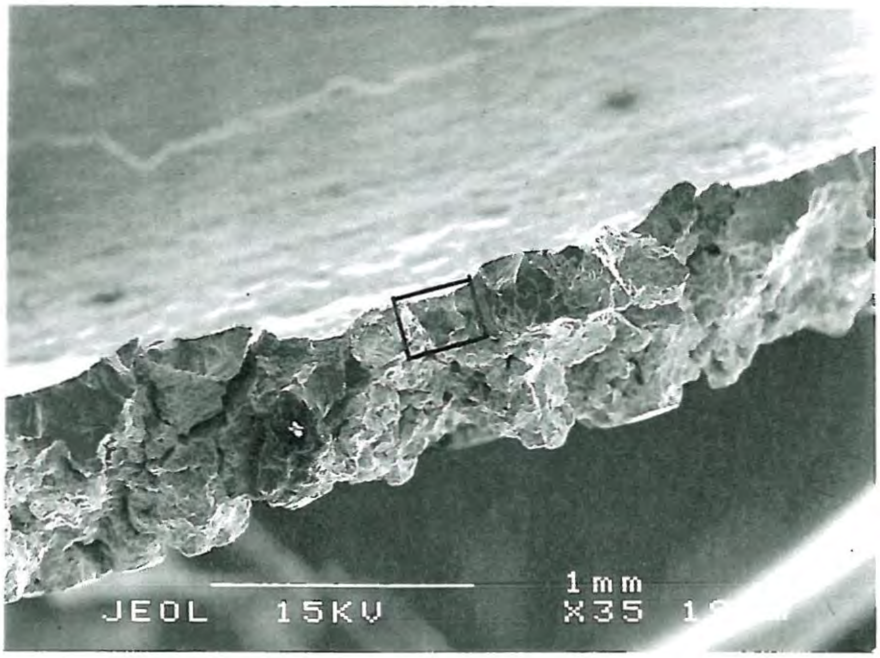


Eroded fracture surface from section S1, close to the section S2.
SEM-photo, magnification x 12.

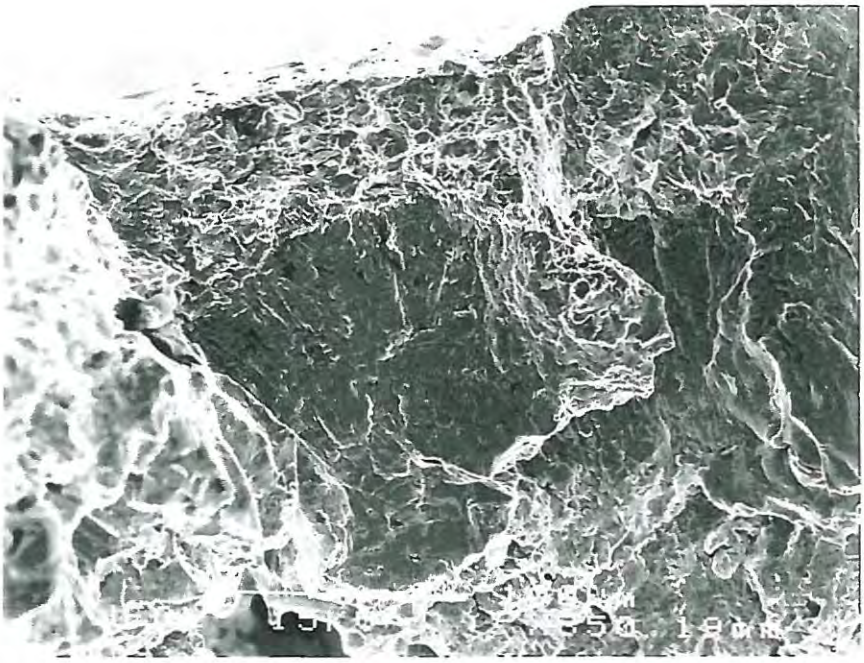
FIGUR 35 A/B



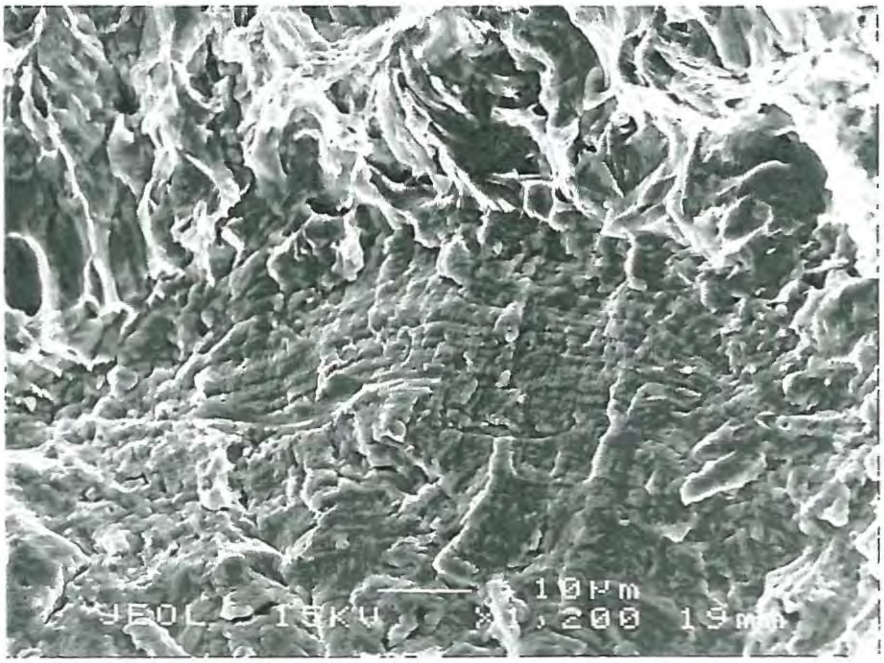
SEM-photo of a fracture micropattern from section S1, showing fatigue striations.
Magnification x 2500.



General SEM view of the section S1 fracture surface. The inner surface of the Ti-strip is located to the upper half of the photo. A close-up of the framed area is seen on the next figure.
Magnification x 35.

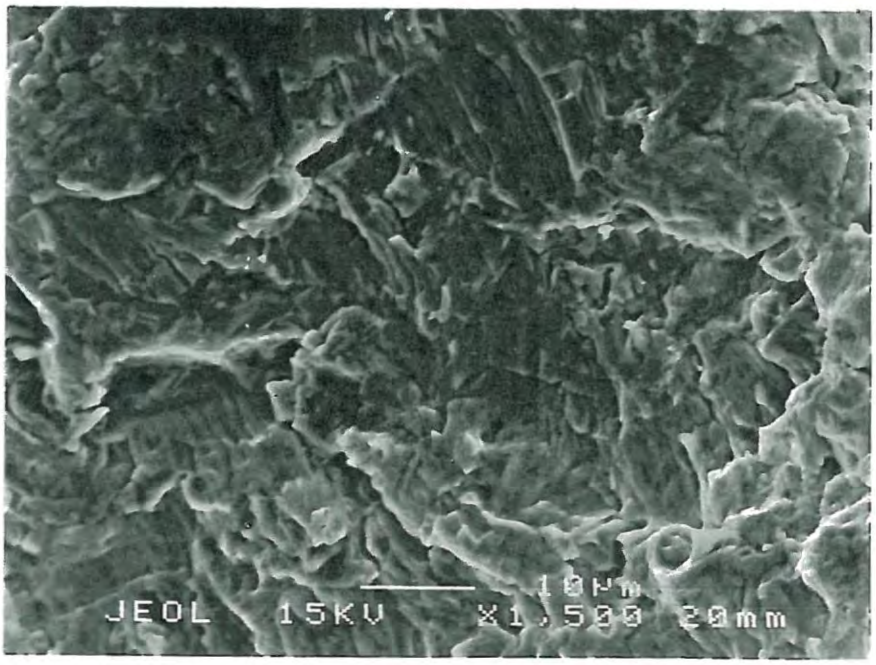


Another smooth fracture surface area in the section S1, detail from the area framed in Fig. 35B.
SEM-photo, magnification x 350.



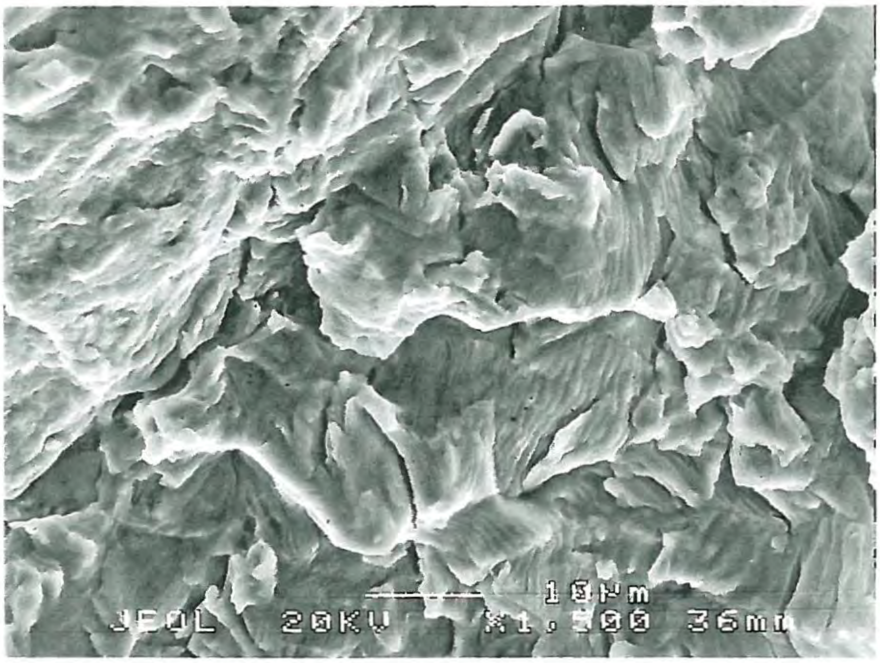
SEM-photo illustrating the transition zone between the fatigue and the final rupture (top of photo) towards the inner surface.
Magnification x 1200.

A transverse crack surface in the protective Ti-strip. The longitudinal fracture through the eroded zone is seen down to the left. Section S3.
SEM-photo, magnification x 13.

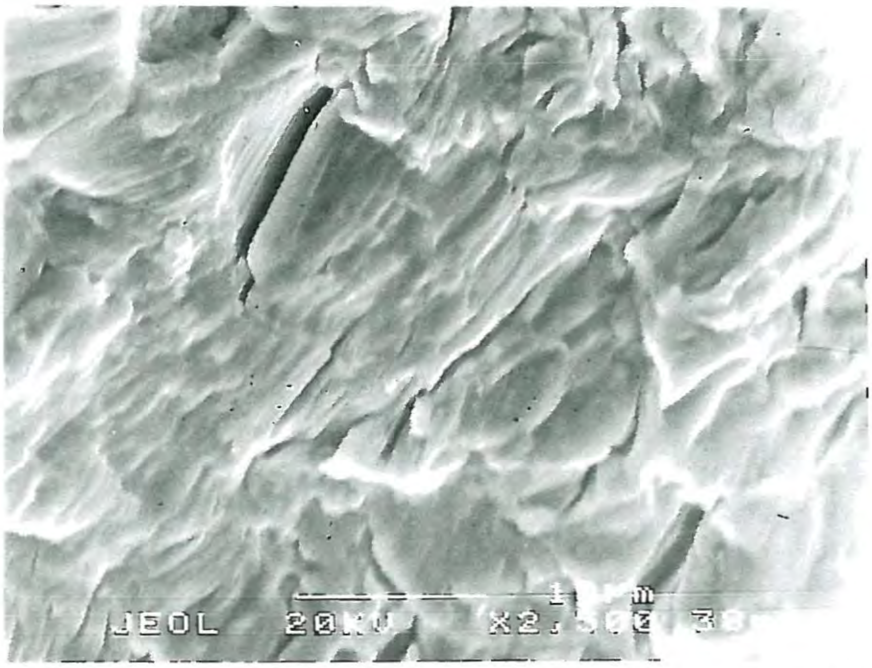


SEM close-up of a local area close to the crack start position seen down to the left in Fig. 37A.
Magnification x 1500.

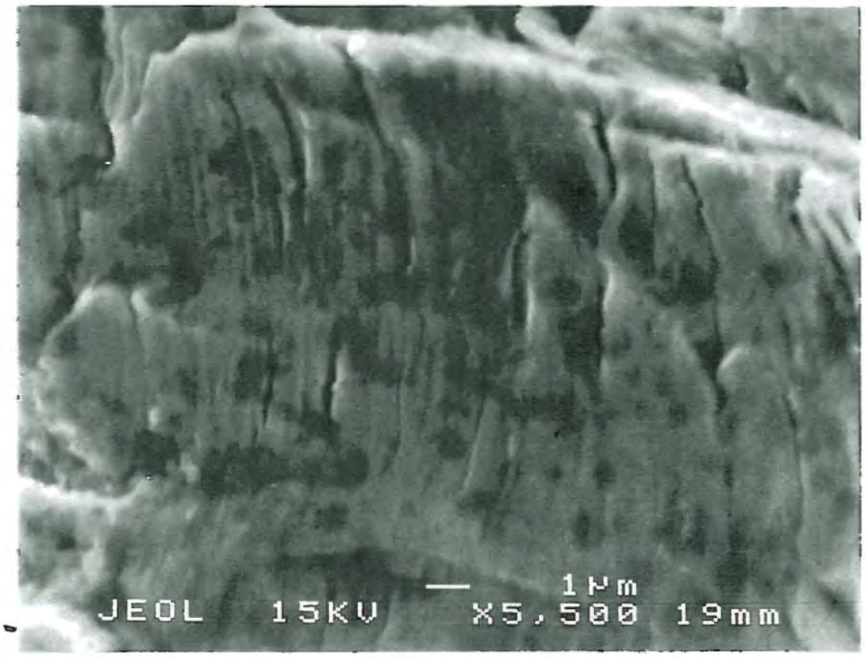
FIGUR 38 A/B



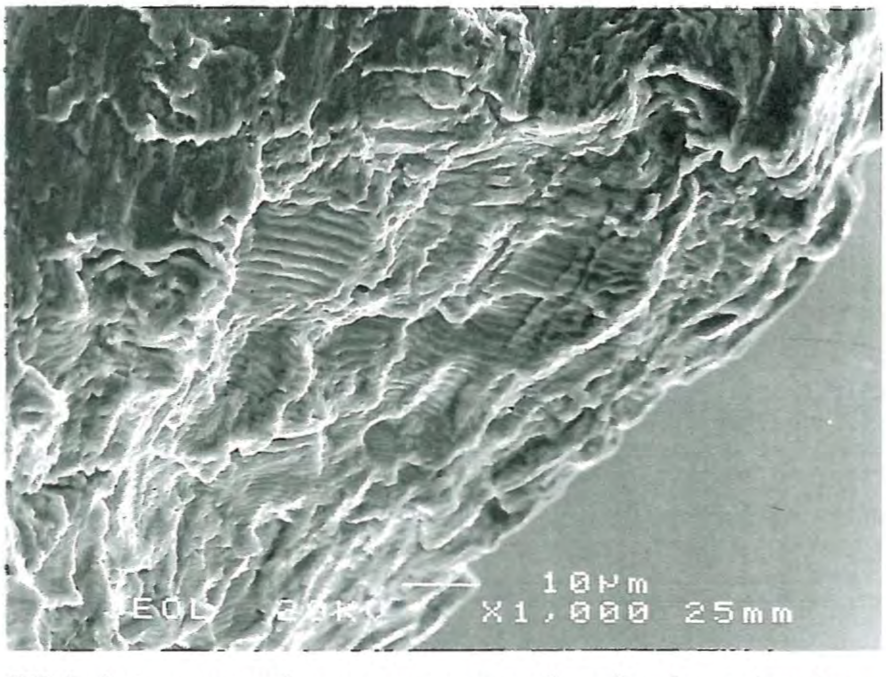
SEM close-up of a local area close to the toe (to the right) of the transverse crack surface seen in Fig. 37A.
Magnification x 1500.



SEM detail photo representing the micropattern close to the crack toe.
A fatigue mode of cracking is seen.
Magnification x 2500.



SEM detail photo representing a local area close to the toe of the transverse crack surface shown in Fig. 37A.Fatigue striations are stated.
Magnification x 5500.



SEM-photo representing a transverse crack surface located to the section S2. The location in question is from the start zone of the crack.
Magnification x 1000.

approx. 86 min. When questioned by the AAIB/N, Eurocopter agreed that one revolution of the main rotor comprises one load cycle.

1.16.5.3 The second crack was examined in a similar way to the first. Here, it was also established that the crack was caused by a fatigue fracture. The load cycles were not counted.

1.16.5.4 Figure 17 shows that cracks had started from both corners of the cut-out section after the Eurocopter Technical Instruction No. 230 modification. The work on removing the section had left behind a certain number of trace marks left by tools. The longest and most open of these cracks were examined along the surface of the crack using the SEM. Again, a fatigue fracture was ascertained even if some of the microstructure was damaged by 'hammering' (see Figure 40A). The unexpected number of fatigue fractures which were discovered in the cracks, and the fact that these cracks were also caused by fatigue fractures along the entire length, led DNV to prepare a sample with a ductile overload in the same material. Figure 40B shows that this microstructure is completely different from the structure in Figure 40A.

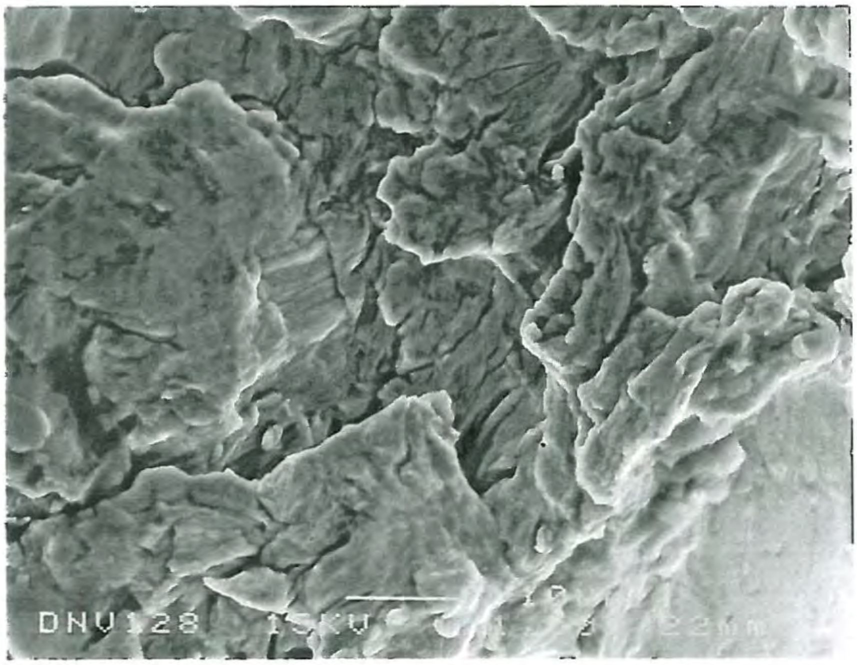
1.16.6 Metallographic examinations of the leading edge strip on main rotor blade S/N 617

1.16.6.1 A cross-section of the main crack in S2 was rubbed down and examined. The results are reproduced in Figures 41A/B and 42A/B. DNV gave the following description of this in its report:

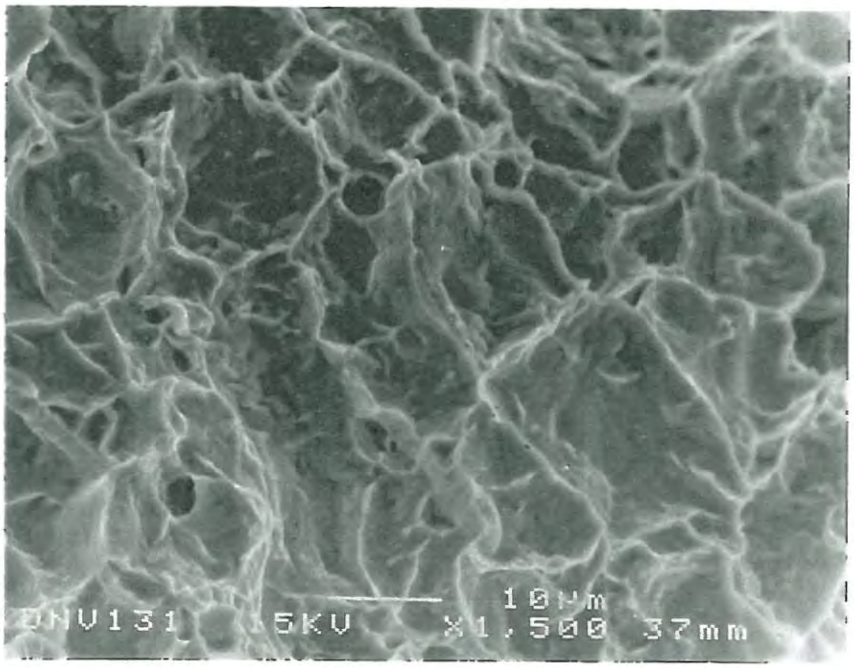
> "It should be noted that in Fig. 142 (AAIB/NFigure 42A) numerous single cracks have started from the severely eroded surface (i.e. from grooves/ cavities) and penetrated the material more or less in straight direction towards the inner (bonding) surface (cracks seen almost parallel). In Fig. 143 (AAIB/N 42B) however, a branched cracking from the bottom location of the grooves/cavities is noted.
>
> Based on the SEM examination of the crack surfaces from the section S2, it should be expected that the majority of the cracks seen in Fig. 140 (AAIB/N 41A) - Fig. 143 (AAIB/N 42B) are fatigue cracks, initiated from the bottom of erosion grooves/cavities propagating towards the inner surface."

1.16.6.2 A section of the leading edge strip was rubbed down to examine the microstructure of the metal. No irregularities were discovered during this examination.

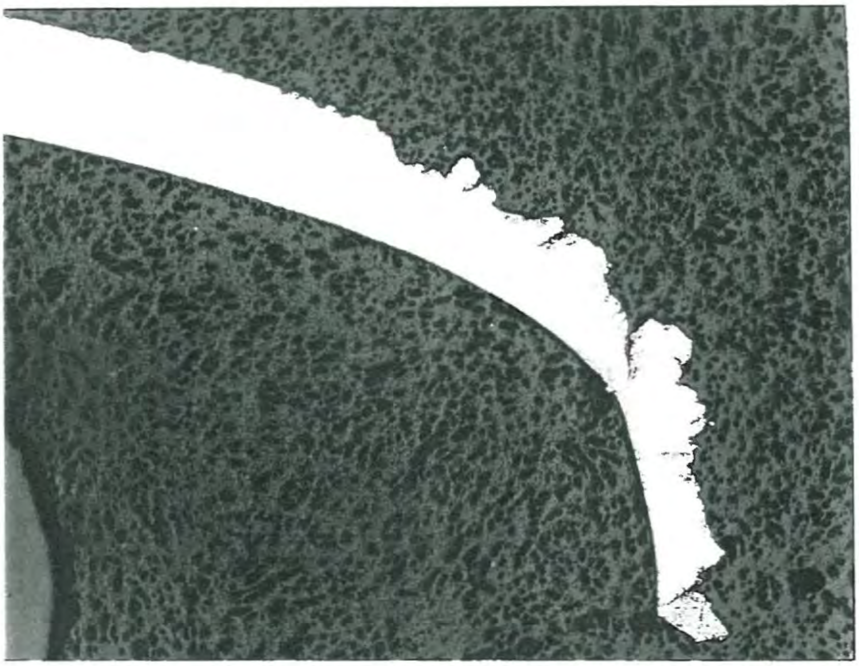
1.16.6.3 Two samples of the leading edge strip were examined using the Vickers hardness tests. A pressure of 1 kg (HV 1) was used. The result indicated a hardness of 151-165, HV5. This is an expected result for T-40/ASTM Ti Grade 2.



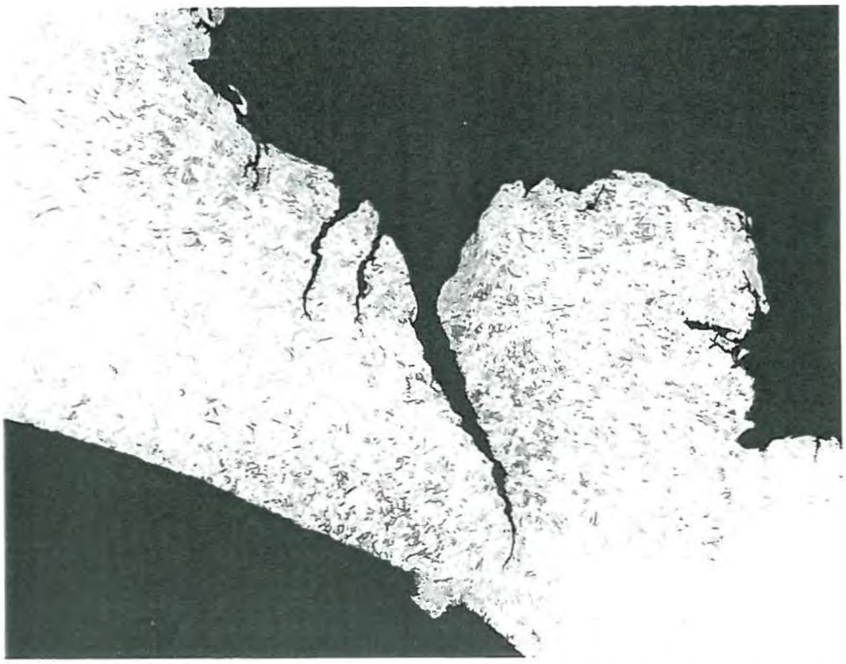
Fracture micropattern at the toe (inner end) of the crack from the modification corner.
SEM-photo, magnification x 1500.



Fracture micropattern for the comparison of fracture mode, ductile material overload made by VERITAS.
SEM-photo, magnification x 1500.



Transverse section through the leading edge zone of the protective Ti-strip.
Magnification x 20.



Close-up photo of a cracked and severely eroded area shown in Fig. 41A.
Magnification x 100.

Micrograph illustrating the situation of erosion and cracking within a local transverse section of the protective Ti-strip, leading edge position.
Magnification x 160.

Micrograph illustrating a branched, local cracking, initiated from the complex geometry of the bottom surface of the eroded pits.
Magnification x 200.

1.16.7 Chemical analysis of the leading edge strip material of main rotor blade S/N 617

Materials Testing (MTS) Norge AS undertook a spectrographic analysis of the material from the leading edge strip. The result showed that the material was within the specifications for T-40/ASTM Ti Grade 2.

1.16.8 Examination of the surface treatment of the inside of the leading edge strip of main rotor blade S/N 617

During the visit to Paulstra in France, DNV had a sample delivered of the grade 100 paper which was used for rubbing down the leading edge strip before application of the primer. DNV prepared a test using this paper, comparing it with the surface treatment given to the leading edge strip of main rotor blade S/N 617. The result of this test is shown in Figure 43A/B. It is worth noting that the strip prepared by DNV is rubbed down using new paper. Tests carried out with worn paper gave results which coincided more closely to the original surface of main rotor blade S/N 617. These tests were also measured using the Mitutoyo Surftest 301 with similar results. The variation in the results was evaluated by DNV as being within what might be expected when various people do the rubbing down, using paper of various grades and degrees of wear.

1.16.9 Mathematical calculation of the bending moment

In an attempt to gain an overview of the forces which may have affected the bending of the fold on the leading edge strip on the main rotor blade of LN-OBP, DNV attempted to calculate the bending moment. The mathematical calculation shows that to attain the necessary bending moment, a surface pressure of 3.2-3.6 kg/cm^2 would be required.

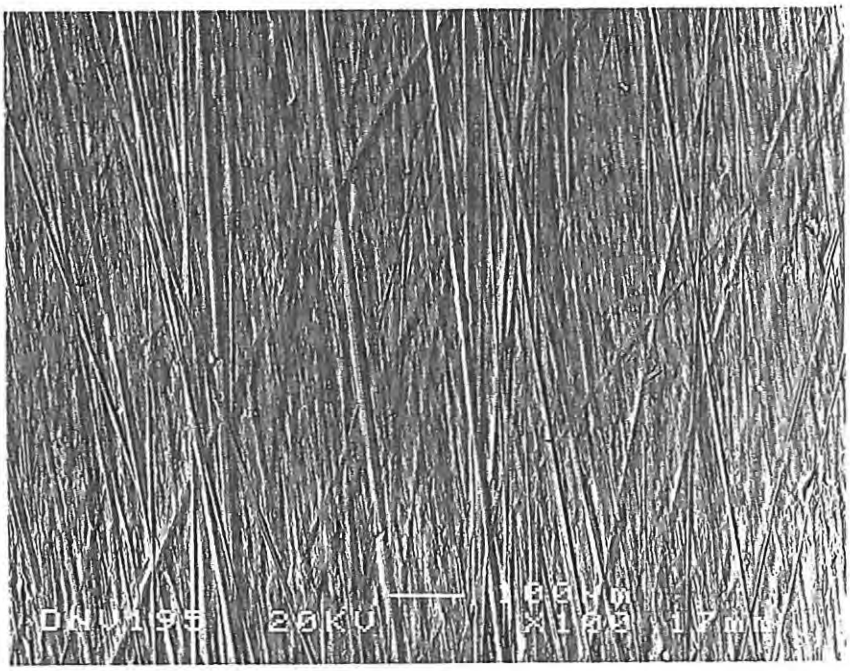
1.16.10 Conclusion of DNV report no. 96-3548

In its conclusion, DNV stated in the report :

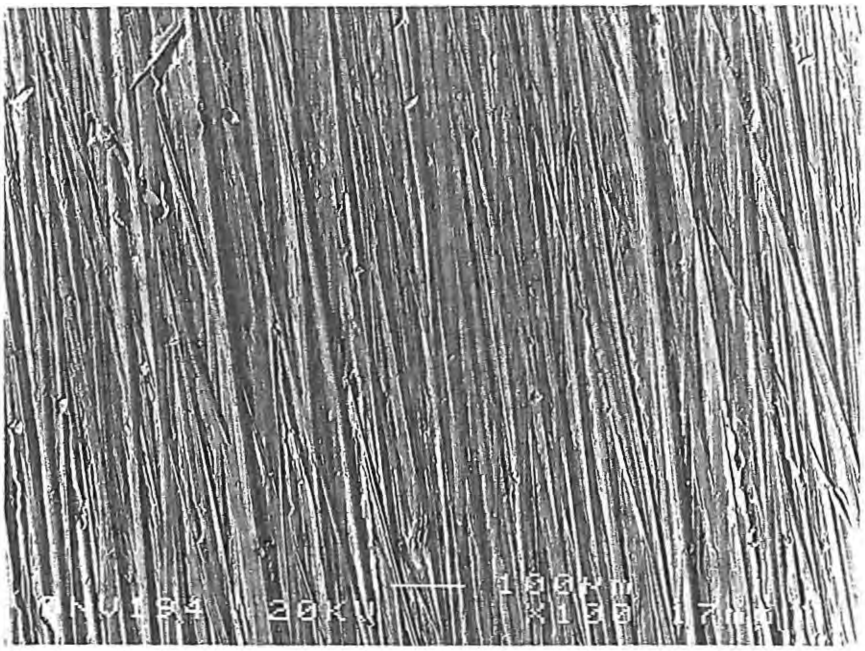
> "The significant leading edge erosion damage, the de-icer return braid modification, and the lack of bonding are all found to be contributors to the vital fold at the outer end of the protective Ti strip."

1.16.11 Examinations of other main rotor blades which have been mounted on helicopters belonging to HS

1.16.11.1 Because of the accident involving LN-OBP, the AAIB/N was given the opportunity to study other main rotor blades which have been taken out of service at HS. Of particular interest were rotor blades S/N 733, 811 and 905. These three rotor blades have all been subject to the Eurocopter Technical Instruction No. 230 modification.



SEM-photo illustrating the rate of original hand grinding undertaken on the bonding surface of the Ti-strip.
Magnification x 100.



SEM-photo illustrating the rate of hand grinding undertaken on the bonding surface of the Ti-strip by VERITAS. Note that a brand new sheet of the specified (100µm) abrasive paper was used by this grinding operation.
Magnification x 100.

1.16.11.2 The leading edge strip on main rotor blade S/N 733 (see Figure 44A) had an operating time of 2,333 hours when the blade was demounted for repair on 28 October 1995. As can be seen from the picture, the strip was perforated with small holes. The picture shows no visible cracks along the strip.

1.16.11.3 The leading edge strip on main rotor blade S/N 811 (see Figure 44B) had an operating time of 1,731 hours when the blade was demounted for repair on 23 October 1995. As can be seen from the picture, the strip was perforated in several places. The picture shows no visible cracks along the strip.

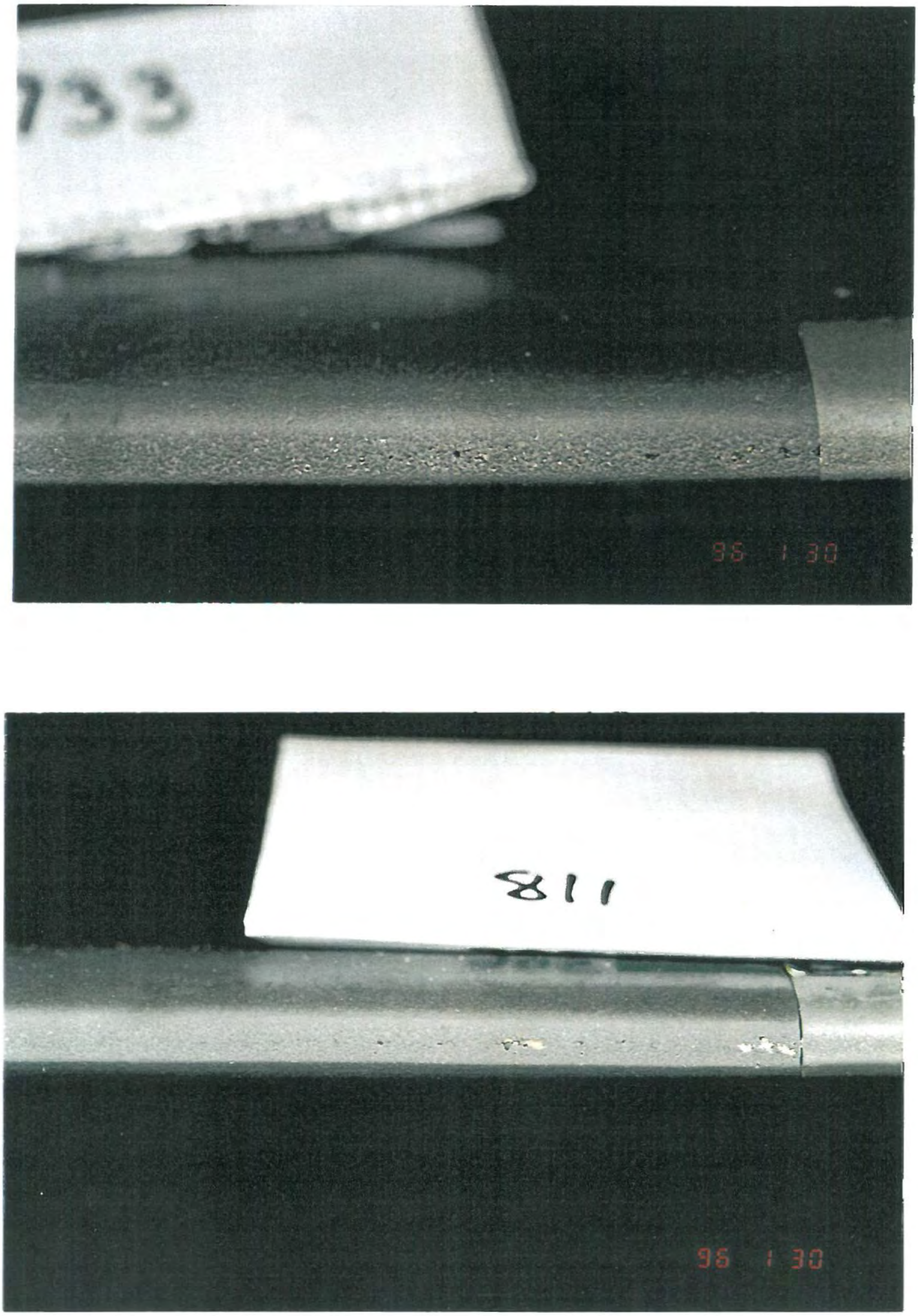
1.16.11.4 The leading edge strip on main rotor blade S/N 905 (see Figure 45A/B) had an operating time of 1,731 hours when the blade was demounted on 23 October 1995. Perforations were then discovered along large sections of the outer part of the leading edge strip. The damage to the leading edge strip was so great that HS decided to remove a part of this to undertake its own investigations. The picture was taken after parts of the strip were removed, showing a pattern which indicates where the leading edge strip had good bonding to the base layer (white), and a grey surface equivalent to that which was discovered below the leading edge strip of blade S/N 617. The picture also shows that erosion had made a hole through the strip and continued into the neoprene, so that the electrical elements in the de-icer element were exposed. According to the information supplied by HS, the leading edge strip had not come loose as a result of this erosion.

As a result of the accident involving LN-OBP, an internal investigation was set in motion at HS to determine the circumstances surrounding the damage to main rotor blade S/N 905. It was then ascertained that the helicopter had been flying for 2:22 hours since its last Daily Maintenance Check and until the damage was discovered. It was further disclosed that no Technical Report had been written based on the erosion damage which was discovered. According to statements from technical management at HS, this situation should have been reported.

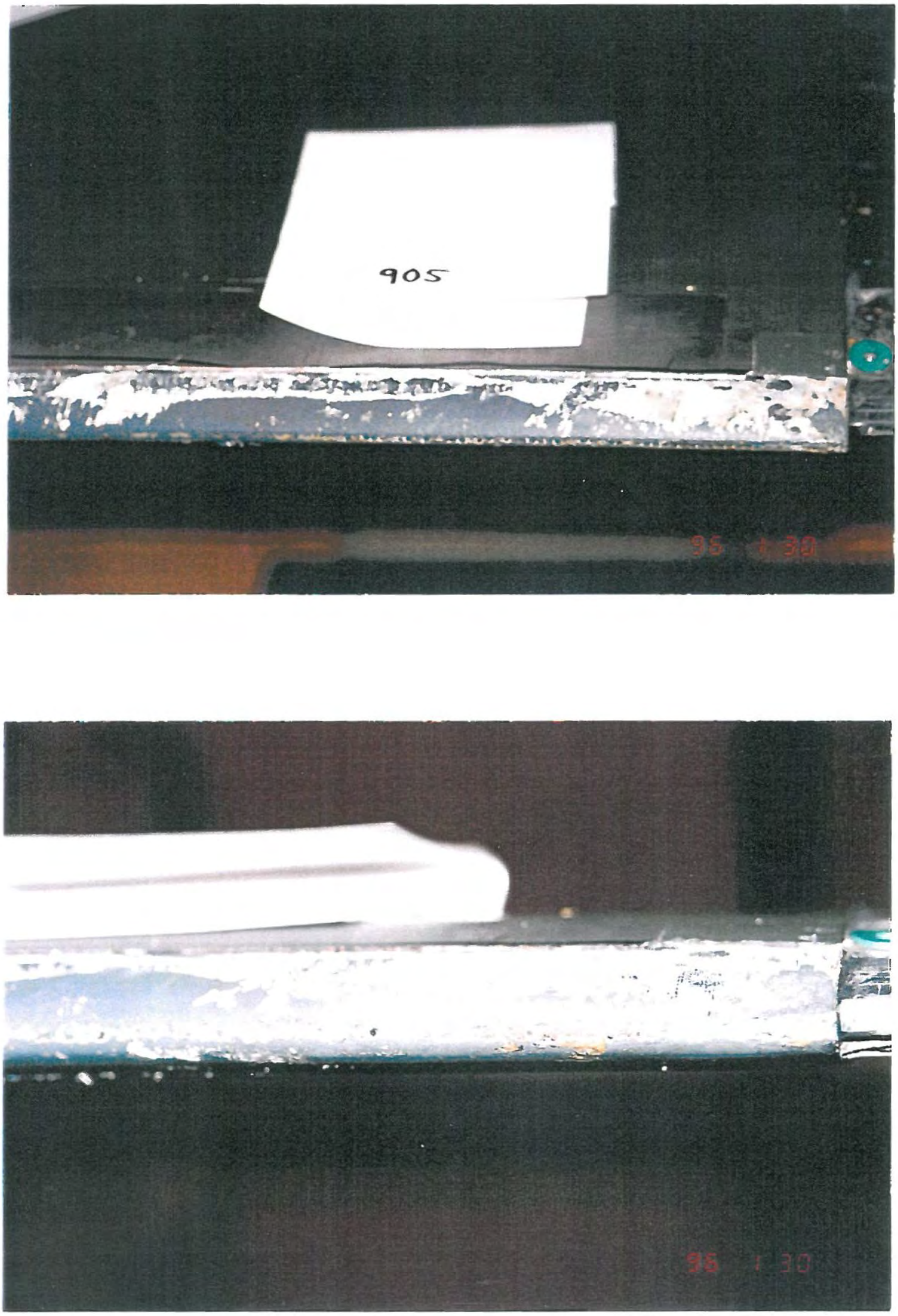
1.16.12 Underwater acoustic transmitter

The combined flight and voice recorder was equipped with an underwater acoustic transmitter (pinger) in accordance with regulations. The purpose of this is to make it possible to locate the recorders if they have ended up on the bottom of the sea/ocean in an accident or an incident which leads to the sinking of the aircraft. In this accident, the salvage crew attempted to search on the frequency given as the normal frequency range for this type of transmitter, but without success. The AAIB/N later had the transmitter examined by its manufacturer, Dukane. In its report after the examination, the manufacturer says that the reason for the transmitter's frequency lying outside the specifications was that internal delamination had occurred in the unit. The reason for this delamination could not be ascertained.

FIGUR 44 A/B



FIGUR 45 A/B



1.17 Organisational and management information

1.17.1 Civil Aviation Administration, Norway

The Civil Aviation Administration, Norway (CAA/N) carries out access checks and inspections of activities of the various airline companies. This also means that the CAA/N approves a company's safety standards as described by means of the company's total manual system and carries out inspections to ensure that this standard is maintained by the organisation.

1.17.2 Helikopter Service AS

1.17.2.1 The company holds the following approvals from the CAA/N:

Licence no. 003
Air operator's certificate 003
JAR-145 approval number 003

In addition, the US aviation authority, the FAA, has awarded the company a Foreign Repair Station certificate (Air Agency Certificate No. CZ5Y797M).

1.17.2.2 As one of the world's leading helicopter operators, the company has built up a comprehensive administration and documentation system in line with the company's size. The term documentation is used to mean, primarily, the company's system of manuals for aircraft operations, aircraft engineering and administration. The system is based on the traditional three-level system, the strategic level (Quality Manual), tactical level (such as the Flight Operations Manual and the Maintenance Operations Manual) and the operational level (the Flight Manuals and Maintenance Requirements Manuals) (see Figure 46).

1.17.2.3 The company's quality system is organised such that there is a Quality Manager in a staff function reporting to the Managing Director. The Quality Manager has been delegated the task of monitoring the company's collective quality system. The flight own appropriate quality assurance systems. The departments have their own quality assurance units woperations and aircraft engineering department is responsible for building up its ith their own managers to handle the establishment and implementation of revisions of these systems.

1.17.2.4 Eurocopter has a permanent 'field representative' based at the company, with an office in the company's administration building at Sola, so that contact is permanent, although usually informal.

INTERNAL MANUALS

Description and use of manuals

The Company issues the manuals shown in Figure 2. The figure indicates the applicable authoritative ranking of each individual manual.

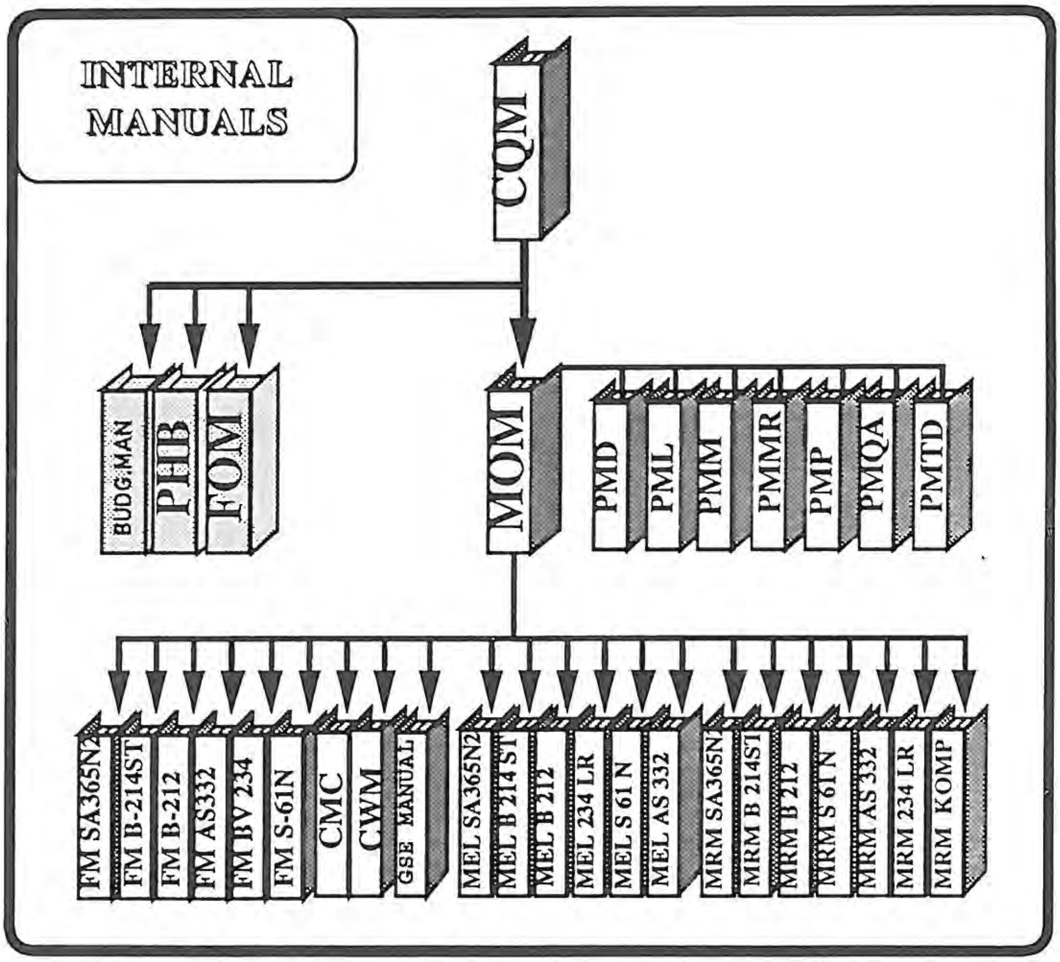


Figure 2

Anyone who becomes acquainted with circumstances indicating that the manuals must be revised is obligated to report this to the responsible issuer.

1.18 Additional information

1.18.1 Establishing aircraft safety standards

The regulations for civil aviation, BSL D 1-1, establish that an aviation company must establish, document and maintain a quality system which ensures that all civil aviation authority requirements, plus internal requirements, are satisfied. These requirements are the company's aircraft safety standards and result in the overall system of manuals for the company. Parts of this system must be approved by the CAA/N, which thereby approves the company's level of aircraft safety.

1.18.2 Maintenance of aircraft - CAA/N requirements

In BSL B 3-2, item 3.3.1, the CAA/N has specified that maintenance and modification of aircraft must be carried out in accordance with a system which has been approved by the CAA/N. The same regulation also states:

> "3.1.2 Maintenance must cover two types of tasks:
>
> a) Routine maintenance
>
> b) Non-routine maintenance
>
> Note 1: Routine maintenance must be carried out at specified intervals. The purpose of routine maintenance is to prevent a degrading of the built-in constructional standard.
>
> Note 2: Non-routine maintenance covers work which results from:
>
> - routine maintenance
> - reporting
> - condition monitoring
>
> 3.1.3 In general, maintenance programmes must include one or more of the following primary maintenance procedures:
>
> - Hard Time
> - On Condition
> - Condition Monitoring
>
> 3.2 The maintenance arrangements must be approved by the Civil Aviation Administration, Norway.

> 8.4.1 Work must be carried out using approved methods and to the standard indicated in the manufacturer's maintenance data. If this does not exist ...."

1.18.3 Maintenance of aircraft - the company's maintenance arrangements

1.18.3.1 In its system of engineering manuals, the company has described how the maintenance system for individual types of helicopters is drawn up, how maintenance is carried out and how it is monitored. The starting point for the maintenance of the company's fleet of helicopters is the manufacturer's instructions. This is in line with CAA/N regulations referred to in 1.18.1. In addition, the company has stated in its system of manuals that its own practical experience should be included as a basis for establishing its level of maintenance. The manuals system describes both major elements of the management requirements as well as general and fundamental rules which have a significant influence on the way in which the maintenance system is constructed, practised and monitored (see Figure 47). From the comprehensive system of manuals, the AAIB/N has chosen to present a number of observations from that part of the system of manuals which contains master documents and which is therefore mandatory, while they are also relevant to this investigation. The observations are taken from the master documents Quality Manual, the Maintenance Operations Manual and associated Procedures Manuals and Maintenance Requirement Manual. The following subdivision has been chosen:

- General
- Programme rules (rules on how the system is constructed)
- Performance
- Revising and monitoring the system

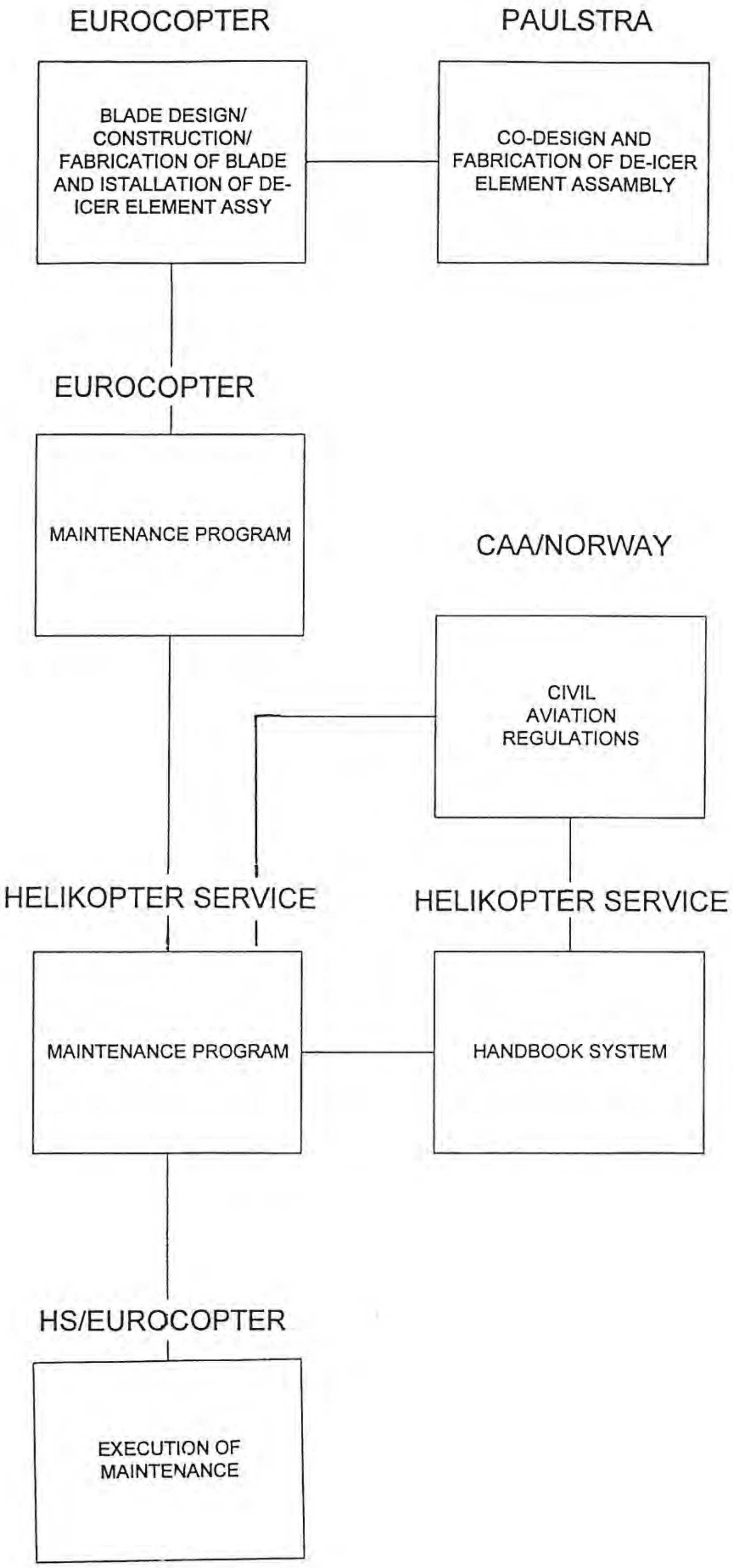
1.18.3.2 *General*

The following can be quoted from the Maintenance Operations Manual (MOM):

> "MOM 06-01-05 General
>
> The purpose of maintenance is to retain the reliability and performance specifications that are built into equipment during its design, manufacture and modification."

> "MOM 06-00-20 Basic Principles
>
> All materials must be safeguarded in accordance with terotechnology principles for good management, communication, resource management, monitoring reliability and costs for the duration of the working life of the materials at Helikopter Service AS."

FIGUR 47


EUROCOPTER
BLADE DESIGN/ CONSTRUCTION/ FABRICATION OF BLADE AND ISTALLATION OF DE-ICER ELEMENT ASSY
PAULSTRA
CO-DESIGN AND FABRICATION OF DE-ICER ELEMENT ASSAMBLY
EUROCOPTER
MAINTENANCE PROGRAM
CAA/NORWAY
CIVIL AVIATION REGULATIONS
HELIKOPTER SERVICE
MAINTENANCE PROGRAM
HELIKOPTER SERVICE
HANDBOOK SYSTEM
HS/EUROCOPTER
EXECUTION OF MAINTENANCE

> "MOM 02-02-20 Main duties, Planning
>
> The Engineering Manager is responsible for execution of maintenance activities in accordance with a defined standard and within the stipulated time frames and resource budgets. The activities must be reflected in a Maintenance Requirement System, the implementation of which is planned in other departments."

1.18.3.3 *Programme rules*

The following can be quoted from the MOM, Procedure Manual, No. 01, Technical Data (PMTD) and the Maintenance Requirement Manual (MRM):

> PMTD, 01-09, Reliability Follow-up General, page 1
>
> "It is the duty of Helikopter Service AS to develop a maintenance program for its helicopters which is suitable for maintaining the reliability which these helicopters have been designed to meet."
>
> "Helicopters like other aircraft are delivered with a maintenance program from the factory. For newer types of aircraft the maintenance programs have been developed on the basis of an interactive process such as MSG2/3. This means that the design and maintenance have been adapted so that the remaining unreliability is within acceptable limits."
>
> "PMTD 01-10, Reliability Follow-up, MSG-2/MSG-3, page 3
>
> The original maintenance programme was derived on the basis of a systematic evaluation process. In the following, MSG-3 logic has been used as the point of departure. For most aircraft operated by HS the factory has not made any introductory MSG-3 analysis. However, a more or less formalised process has been carried out to define the maintenance program for all aircraft."
>
> "MOM 06-00-20, Execution, Basic Principles
>
> The Maintenance program must only contain items that satisfy 'MSG-3 Applicability and Effectiveness Criteria' (See MSG-3 documentation).
>
> The consequence analysis must follow a 'Top Down' method (MSG-3) in which an evaluation of how the main system can fail is made first, then the subsystem and finally the component and detail."
>
> "PMTD 01-10, Reliability Follow-up, MSG-2/MSG-3, page 4
>
> HS has based its maintenance program on the three maintenance processes in accordance with FAA Advisory Circular 120-17a. The maintenance processes are the same as mentioned in the discussion of MSG-2 above. The processes

> are discussed on Page 1 of the HS Maintenance Requirement List for all aircraft types."

NOTE

When HT (Hard Time) and OC (On Condition) are listed as maintenance procedures against the relevant main rotor blade in the company's Maintenance Requirement List, reference is made to the following entry from the PMTD concerning OC (the AAIB/N's comments). Quote:

> "On-condition maintenance implies that information on the condition of a component or system is used to control the maintenance actions. If the method for checking the condition is adequate (i.e. both the technology and interval) a failure will be detected before it results in a critical situation and corrected. All maintenance actions will be planned then.
>
> The rate for unplanned maintenance actions is thus an expression of the fact that:
>
> - The technology for failure detection is not adequately reliable
> - The inspection/test interval is too long in relation to the failure development rate." End quote.

> "MOM 06-01-05 Execution, Maintenance System, General, page 2
>
> Our planned maintenance program is documented in the Maintenance Requirement Manual (MRM). This is designed according to a logical method based on the equipment's normal function and how it can malfunction and what effect each individual malfunction can have on safety and economy.
>
> Maintenance for which there is no documentation that is based on the equipment's reliability characteristics, i.e. its malfunctions types, frequency and probability as a function of its service life, age, costdata, etc. must be analysed again on the basis of the information that is currently available."

> "MRM AS332L1 00-01-00, page 1
>
> The purpose of this Maintenance Requirement Manual is to document the maintenance programme for the helicopter and its components. The documentation is based on the initial maintenance requirements set by the helicopter manufacturer and the certifying agencies. This together with the operational environment and experience, forms the basis for the issue and development of a preventive maintenance program documented in this MRM."

1.18.3.4 *Performance*

The following quote is taken from the Maintenance Operation Manual (MOM):

> "MOM 06-00-20 Execution, General, Basic Principles, page 1
>
> All work must be performed in accordance with approved procedures or established HS quality standards.
>
> The quality requirements for work must be known to and understood by whoever manages and performs the work"

> "MOM 06-03-10 Execution, Implementation, General
>
> When individual work tasks are carried out the work supervisor must ensure that the assigned tasks are delegated in such a manner that the necessary technical competence is present.
>
> Each individual must carry out the task so that the defined quality is achieved. Inspection of own work must be a natural part of all work.
>
> The supplemental control function must confirm that the defined quality has been achieved.
>
> Nonconformity must be followed through so that corrective measures can be taken."

> "MOM 06-03-20 Execution, Implementation, Control and Management of maintenance work, page 1
>
> The performance of maintenance work on aircraft and components must be based on approved specifications, and it must be carried out in accordance with the stipulated instructions and procedures through the use of qualified personnel and the correct tools and equipment."

1.18.3.5 *Revising and monitoring the maintenance system*

The following quote is taken from the quality manual (HFK - also known as CQM, see Figure 46) and the Procedures Manual - Technical Data (PMTD):

> "HFK 01-01-15, Technical Director
>
> The director has been personally approved by the CAA/N as being responsible for the technical supervision of the work carried out in the workshop and is in control of the production process in which safety is of central importance. This includes a reliability testing programme which is attached to the Maintenance Review Board which ensures the formal basis for adjustments to maintenance programmes and processes.

The director's steering document is the Maintenance Operation Manual (MOM) together with auxiliary procedures manuals.

"HFK 02-00-01 Quality System, General, Quality Assurance, page 1

To attain its overall objectives, Helikopter Service AS has an integrated quality assurance system.

Quality assurance must ensure that the company's organisation, including suppliers and customers, works towards attaining quality by means of the systematic monitoring of all activities. The attained level of quality must be assured by means of verification and documentation."

"HFK 02-02-01, Instruction, ASB (Aviation Safety Board)

The intention of the ASB is to monitor the company's risk level with regard to operational and engineering incidents, based on information from nonconformity and audit reports."

"PMTD 01-07, Reliability Follow-up-Description, Purpose, page 1

Maintenance at HS must follow the principles of Reliability Centred Maintenance, RCM (Reliability Controlled Maintenance). This means that the reliability of the aircraft must be kept within acceptable limits through a maintenance program that gives optimal economy. The purpose of reliability follow-up is to monitor the results of the maintenance program and its implementation at HS with the aim of maintaining acceptable helicopter reliability by means of adequate maintenance".

"PMTD 01-08, Reliability Follow-up MRB, Purpose

The objective of HS is to ensure that the planned maintenance functions in the best possible manner to achieve reliable operation of helicopters.

The MRB must ensure that the targeted criteria for operations and maintenance of helicopters is maintained.

By actively using empirical data from operations and maintenance requirements, specifications and implementation of maintenance processes must be continuously updated.

The MRB must ensure that important problems not covered by the established administrative procedures and of long-term significance are revealed and dealt with."

PMTD 01-08, Reliability Follow-up MRB, page 2

The MRB(T) is responsible for:

- Conducting quarterly reliability reviews of empirical data in order to recommend preventive measures.

- Measuring the effectiveness of the existing maintenance program and specifications."

1.18.4 The company's technical manuals - other observations

1.18.4.1 On examining the master technical manuals, the AAIB/N has highlighted several other statements of a more general nature, such as:

> "MOM 02-02-01, Functional Description, Vice President Maintenance and Engineering.
>
> The Vice President Maintenance and Engineering is responsible for living up to the company's Internal Control System which encompasses duties involving health, safety and working environment for all employees in his/her area.
>
> In accordance with the regulations in JAR-145, he can delegate responsibility to his department managers and staff functions......"
>
> "MOM 03-10-10, Quality Assurance Elements, Basic Principles, page 1
>
> The governmental laws and regulations have established the minimum requirements to Safety that shall be met by air transport companies. The authorities require air transport companies to have an Internal Control system for assuring that the requirements of either side are being met. The Quality Assurance System of the Company shall take care of these requirements."
>
> "MOM 03-10-10, Quality Assurance Elements, Basic Principles, page 1
>
> The word Quality is defined as a result of an activity that is in a condition that it was preliminary set to be.
>
> By coordinating the different QA requirements to a total, so this requirement will cover all necessary functions to produce all our products and services, we have got our QA System.
>
> The responsibility for the Company's total QA System, is delegated to the Quality Assurance Manager.
>
> QA takes it for granted that we are looking on the next part of the production chain as our Customers."

1.18.4.2 During examination of the books, it has been discovered that there are several printing errors and missing figures, where these have been referred to.

1.18.4.3 It should be noted that the Technical Director and line managers immediately below him, have the MOM plus associated procedures manuals as master documents, apart from the manager of the Engineering Department, whose instructions do not contain references to the master documents.

1.18.5 Maintenance data

1.18.5.1 The helicopter's main rotor blades were maintained in accordance with maintenance data developed by the manufacturer, Eurocopter. In this maintenance data, the main rotor blades were subject to maintenance based on the helicopter as a whole and directed specifically at the main rotor blades as an independent unit.

1.18.5.2 As an air operator, HS has developed a maintenance system which builds on the maintenance data prescribed by Eurocopter, as well as the Norwegian aviation regulations and in-house practical experience. This will be described more-thoroughly below, where the maintenance data for Eurocopter and on the part of HS will be described in detail.

1.18.6 Maintenance data from Eurocopter

1.18.6.1 Eurocopter describes the helicopter's maintenance programme in 'Master Servicing Recommendations' (Also abbreviated to PRE by Eurocopter). Chapter 05.21.00 describes the Daily Checks, which are subdivided into:

- Check before the first flight of the day (B.F.F.). This is described as follows:

  "This inspection is intended to ensure that the aircraft is flightworthy following overnight parking and preparation at the airfield, and therefore any reconditioning work."

- Turnaround check (i.e. one for each flight) (T.A.). This is described as follows:

  "The purpose of this check is to detect possible consequences of flight at the earliest possible time."

- Check after the last flight of the day (A.L.F.). This is described as follows:

  "This check is intended to determine whether the aircraft can be scheduled for the next day of flying. It takes place after a post-flight check and after any work undertaken as a result of crew reports or abnormalities found on the ground.

Aircraft documents must be accurately filled in after this inspection."

1.18.6.2 Check before the first flight of the day (B.F.F.) is described in the maintenance data MET 05.21.00.601. The following is entered under the heading PRELIMINARY STEPS:

"Set up access ladders to:

- The transmission deck as per version.
- The TRH: When setting up the ladder, handle it with care to ensure that it does not hit the tail rotor blades. (The same precautions should be taken when the ladder is removed)"

The following mention of inspection of the main rotor blades is entered under the heading CHECK:

"- Main rotor blades - Visual check at distance, no dents"

PRE also refers to 'Checking the optional equipment' with reference to the maintenance data MET 05.21.00.604. In this manual, Rotor De-icing is listed as a type of equipment which requires a special inspection. The inspection is not described specifically for the B.F.F, but should be carried out on each flight according to item 10:

"10 <u>ROTOR DE-ICING</u> (STATIONS 3, 5 and 8)

10.1 <u>On Each Flight</u>

Perform a general inspection of the system (condition attachment)."

As an introduction, the manual describes the fact that the work should be carried out with : "Special tools: None". (See Figure 48 for reference to stations 3, 5 and 8).

1.18.6.3 The turnaround check (T.A.) is described in the maintenance data MET 05.21.00.602. According to this, the main rotor blades must be inspected:

"Visual check for dents from ground."

According to MET 05.21.00.604, optional equipment must be inspected in the same way as for B.F.F.

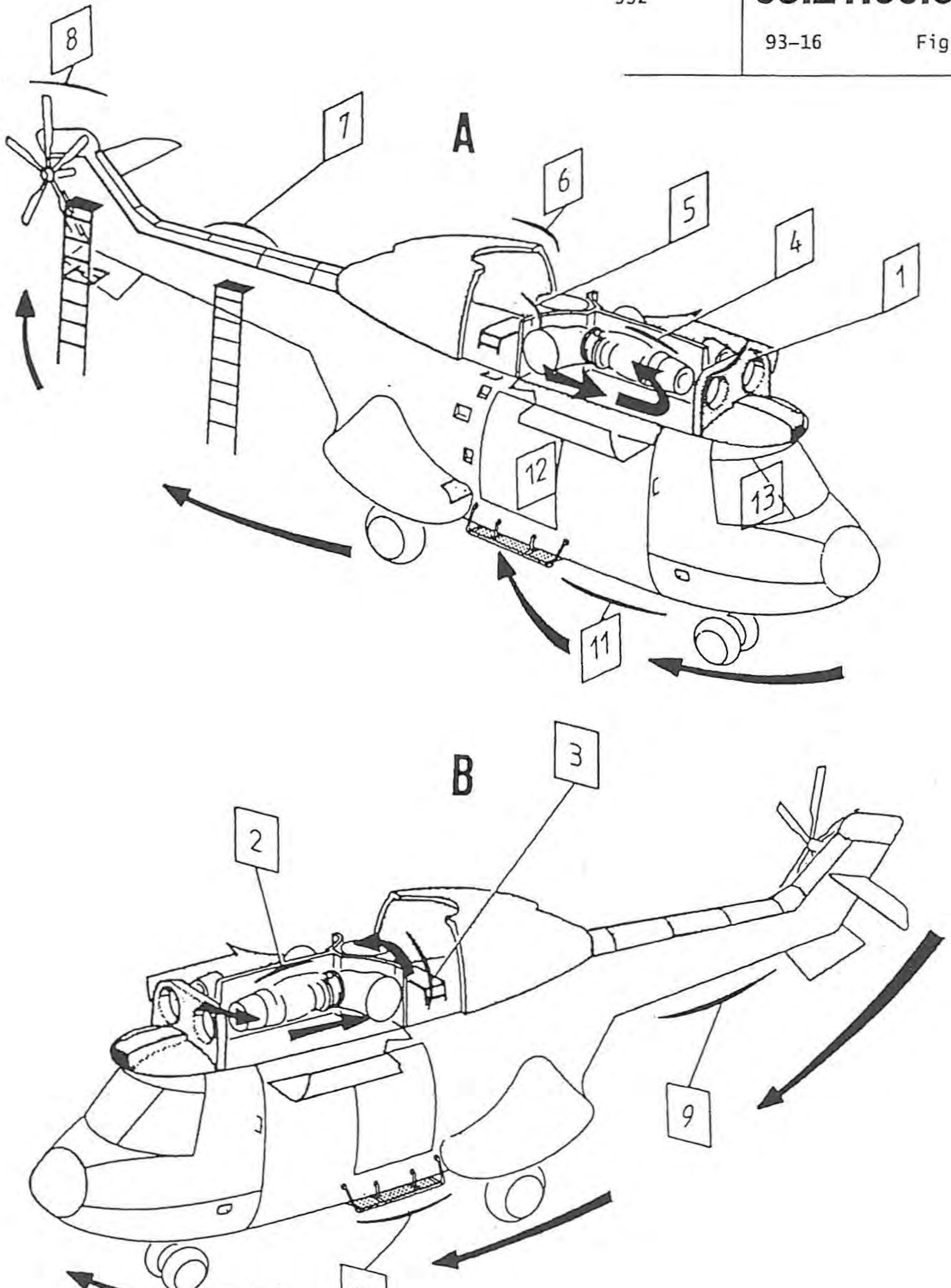
1.18.6.4 The Check after the last flight of the day (A.L.F.) is described in the maintenance data MET 05.21.00.603. As an introduction, it is explained that the inspection

FIGUR 48

332

05.21.00.603

93-16 Fig. 1



should be carried out without special equipment, but with a ladder up to the transmission deck. A section including a general description of the work involved in the A.L.F. does not give any information about inspecting the rotor blades. In addition, to quote:

> "6 CHECK STATION 3 - M.G.B. AND MAIN ROTOR, L.H. SIDE
>
> 6.1 M.G.B compartment: cleanliness
>
> 6.2 Main blades: general condition - skins - TE strips - tabs - stainless steel protection (visual check: delamination - impacts - scoring - cracks - distortion)
>
> : condition of protective strips (lower surface): bond separation - blisters - cuts.
>
> CAUTION: IF ICING CONDITIONS HAVE BEEN ENCOUNTERED IN FLIGHT CAREFULLY CHECK THAT THERE ARE NO DENTS ON THE FOLLOWING:
>
> - underside of main blades
> - tail blades
> - horizontal stabiliser
> - cowlings
>
> On main rotor blades 332A11.0022, 332A11.0024, 332A11-0030, all dash numbers, carry out a daily visual check of the trailing edge section between 100 and 700 mm from the blade attachment bushings.
>
> - if a succession of small spaced defects (Morse-code type sentence) (detail of defect: fig. 2, item 7) is found at the joint (8), check evolution of the defect. (See Work Card 62.10.00.603)."

The description of the inspection for the right-hand side is identical with regard to the main rotor blades.

'Checking the optional equipment' MET 05.21.00.604 has a supplement for Rotor De-icing which applies to the A.L.F. Quote:

> "10.2 After the Last Flight of the Day
>
> INSPECTION OF STATION 3 and 5 - MGB and MAIN ROTOR
>
> Main rotor blades: - Condition of leading edge protective strip: bonding separation - impacts - deformation - cracks......

- Condition - locking of electrical connectors - cable loom and bonding wires."

1.18.6.5 In Chapter 05.22.00, PRE lists an inspection which applies to the helicopter and which must be carried out every 100 hours. This inspection does not apply to blades with the part number in question.

The more major inspections listed in PRE, and which deal with the helicopter, do not contain any maintenance items concerning the main rotor blades. The remaining inspections should be carried out on the basis of times set for each individual main rotor blade.

1.18.6.6 The next inspection which is listed in the PRE, and which deals with the helicopter's main rotor blades, has an interval of 500 hours. The text in Chapter 05.23.00 reads: "Detailed check of main rotor blades, without blade tip removal." and the relevant basic data reference is MET 62.10.00.603 excluding § 8. (This is a printing error, it should read § 9, AAIB/N comment.) This is the basic reference data for all maintenance of the main rotor blade in question (see Appendix 2).

An 18 calendar month inspection in Chapter 05.33.01 deals with main rotor blades, and reads as follows: "Detailed check of main rotor blades, with blade tip removal". This also has a reference to MET 62.10.00.603.

PRE Chapter 05.41.00 states that the main rotor blades must be inspected in accordance with MET 62.10.00.603 excluding § 9, 50 and 200 hours respectively, after the installation of new, overhauled or repaired blades.

1.18.6.7 Under Chapter 05.52.00, PRE deals with Severe Climate Conditions. This lists:

- Tropical and Damp Atmosphere
- Salt-laden Atmosphere
- Sand-laden Atmosphere
- Cold Weather

Under Salt-laden Atmosphere, it prescribes that the rotor blades should be washed in accordance with MET 60.00.00.304 every 25 hours, and that the helicopter's structure should be washed with fresh water every 7 days. If used for hovering and flying at low altitude, the helicopter's structure should be washed during each A.L.F. A Salty Atmosphere is defined as :

"- Aircraft based on board ship or operating more than 50% of its time within 1 km from the coast.

or

- Aircraft operating more than 50% of its time over the sea at low altitude (less than 1,000 ft)."

Under Sand-laden Atmosphere, it prescribes that the rotor blades should be checked for erosion in accordance with MET 62.10.00.603 (visual check) every 10 hours.

1.18.6.8 'Main blades into storage and removal from storage' MET 62.10.00.901 provides information about the storage of main rotor blades. According to the information given there, the blades should be inspected in accordance with MET 62.10.00.603 when they are removed from the store.

1.18.6.9 After the accident, Eurocopter France issued Telex Service 10009/0045/96, dated 14 February 1996. This describes the following supplement to the A.L.F:

> "During the check at station 8
>
> (Tail rotor transmission - tail rotor)
>
> Bring each main rotor blade onto the tail boom centerline and check that there are no perforations in the leading edge metal protective strip, in particular at the blade tip approximately 1 meter (This way the operator is positioned at a suitable distance to carry out the check)."

1.18.7 Maintenance data at Helikopter Service AS

1.18.7.1 The helicopter was maintained in accordance with the maintenance programme drawn up by HS. This is described in the company's Maintenance Requirements Manual (MRM). This has been approved by the CAA/N. As mentioned previously, this programme is based, to a large degree, on the maintenance data from Eurocopter.

MRM Chapter 2 Daily Maintenance Checks covers:

- A Pre-flight Check (PFC)
- B Daily Maintenance Check (DMC)

1.18.7.2 The following entry is included about the company's Pre-flight Check (PFC):

> "To be performed prior to each helicopter departure in accordance with the Pre-flight Check List in MET 05.21.00.601 and Checking the Optional Equipment in MET 05.21.00.604 when operating from established onshore bases and whenever an ICAO type II Technician is available."

In practice, this inspection replaces both the B.F.F. and TA inspections described by Eurocopter.

1.18.7.3 The following entry is included in the company's Daily Maintenance Check (DMC):

> "The DMC shall be carried out under the responsibility of a Licensed Aircraft Technician (ICAO Type II) AS 332 at intervals not to exceed 24 clock hours or 10 operating hours.
>
> Perform the inspection in accordance with Daily Maintenance Check located in this MRM Chapter 00-06-00 and expanded lists Check After Last Flight of the Day in MET 05.21.00.603 and Checking Optional Equipment in MET 05.21.00.604."

The company's DMC is designed as a checklist in which the main rotor blades are included as follows:

> "Main Rotor Blades ... GVI"

The GVI is described as follows in the company's MOM, Chapter 06-00-30, page 5:

> "GVI = General Visual Inspection
> The General Visual Inspection is a visual inspection to evaluate a technical standard/condition combined with physical contact and measurements (when required) under the following conditions:
>
> - The distance to the relevant parts/components must permit physical contact when necessary in order to determine the condition of the material.
> - Work platforms etc. are used as required.
> - Doors and hatches are opened or dismantled to enable physical contact.
> - Removal of parts or components is not normally carried out.
> - Cleaning may be necessary. Oil and grease must be wiped away. An attempt must be made to determine the cause of oil or grease spots and necessary repair evaluated.
> - The aids used are normally a light and mirror. Additional lighting and equipment is used as required."

1.18.7.4 The next inspection prescribed in the MRM, and which is relevant to the helicopter, is an SMC 1S1 (50 hour) inspection. This does not contain any items which deal with the main rotor blades.

1.18.7.5 SMC 1S 75 HOUR CHECK is relevant to the helicopter and must be carried out every 75 flying hours, according to the MRM. The following is entered under Subtask No. 927:

"INSPECTION OF MAIN ROTOR BLADES.	Doc. ref. info.
1 Clean Main Rotor Blades using mild detergent	MET 60.00.00.304
2 Perform a visual inspection of Main Rotor Blades for general condition	MET 62.10.00.603"

This inspection is not a Eurocopter requirement, but it accompanied the helicopters as part of the maintenance programme after the take-over from Braathens Helicopters AS, and has since then been included as part of the maintenance programme at HS.

The more major inspections listed in the MRM, and which deal with the helicopter, contain no maintenance items concerning the main rotor blades (components). The remaining inspections should be carried out on the basis of time intervals set for each individual main rotor blade.

1.18.7.6 The company's maintenance system for components is linked to a computer tool. Part of this tool is a database containing the Maintenance Requirement List (MRL). Among other things, this contains a summary of the maintenance requirements to which each individual component is subject. A report of this list, dated 19 January 1996, for P/N 332A11-0030-09 showed:

"500 H	Perform inspection of Main Rotor Blade I. a. w. MET 62.10.00.603, EXCEPT 'Inspection; 4. Tip Components all blades, Tip Cap removed'. Tolerance limit: ± 50 hours.
18 MO	Perform inspection of Main Rotor Blade Tip Cap Components I. a. w. MET 62.10.00.603, ONLY 'Inspection; 4. Tip Components all blades, Tip Cap removed.'
20000 H	Replace Main Rotor Blade i.a.w. MET 62.10.00.401."

1.18.7.7 After the emergency landing, the company has issued several revisions of the basic maintenance data for the AS 332L/L1. HS revision 244E describes the fact that the Main Rotor Blade Leading Edge metal protective strip must be inspected from a 'normal reading distance' during the DMC. The DMC checklist has been changed accordingly:

"Main Rotor Blades DVI"

The DVI is described in the company's MOM, chapter 06-00-30, page 3, as a Detailed Visual Inspection.

1.18.8 Performance of maintenance work at Helikopter Service AS

1.18.8.1 HS has divided maintenance work into three levels:

- Line Maintenance
- Base Maintenance
- Workshop Maintenance

The company's Pre-flight Check and Daily Maintenance Check are normally included in the work carried out at the Line Maintenance level. The AAIB/N interviewed the two technicians who carried out the last PFC and DMC, respectively, on the helicopter in question prior to the accident. These conversations gave the impression of a good level of understanding of the maintenance data which was applicable to the performance of the inspections. The relevant expressions from the maintenance data 'Visual check at distance, no dents' and 'Perform a general inspection of the system (condition attachment)' (Ref. 1.18.6.2) and 'GVI' (Ref. 1.18.7.3) were all understood to be inspections which could be carried out at a distance without being able to touch the inspection point. The technicians were also in agreement that the A.L.F. (MET 05.21.00.603) required only the blades to be inspected from stations 3 and 5 (see Appendix 2). There was further agreement about the fact that one of the criteria for changing rotor blades was the existence of holes in the leading edge strip. The term 'holes' meant any hole which was visible to the eye. There was agreement on the fact that it was difficult to evaluate erosion along the leading edge strip from ground level (see Figure 49) or from stations 3 and 5 beside the rotor head.

One of the technicians was not familiar with the fact that the company had carried out a modification on the blade in question, the second of the two was familiar with the fact that the rotor blade had been modified, but was uncertain about what the modification entailed. According to information given by the HS technical management, Teknisk Avdelingsinformasjon (TAI) [Technical Department Information] or Maintenance Alert Notices, MAN, are used to provide company technicians with information. However, they had not been given any information about the modification in question. The company gives the reason for this as being that the modification was of no significance to the technicians or to maintenance in general. The management's opinion is therefore that it was not necessary to provide any information.

1.18.8.2 After talking to several technicians in the company, the AAIB/N gained the impression that, during the DMC, many of them inspected the outer part of the main rotor blades at the same time as the tail rotor was being inspected. The inspection of the tail rotor was carried out from a work platform beside the tail rotor, and as long as the main rotor was able to swing freely, this provided better opportunities for inspecting the main rotor blades at close quarters. The company technicians additionally expressed the opinion that there were few problems with the

FIGUR 49

maintenance of the de-icer blades and that the titanium strips were more resistant to erosion than steel strips.

1.18.8.3 The company has stated that the rotor blades were washed during the DMC when this was necessary owing to salt deposits. The blades were rinsed with water at low pressure, from a position at station 3 and 5 (see figure 48).

1.18.8.4 The SMC 1S 75 HOUR CHECK was usually carried out at Line Maintenance level. During this inspection, the blades were washed with mild soft soap by technicians/ skilled workmen.

1.18.8.5 The inspections for every 500 blade hours and the calendar inspection at 18 months were usually carried out at Base Maintenance level, with the blades installed on the helicopter. The last 500 hour inspection of the blade in question was carried out in the hangar at Sola without special remarks. MET 62.10.00.603 does not set any qualifications requirements for the person who is to carry out the Bonding Checks by Tapping (see Appendix 2), but the inspection must be carried out using an 80 mm x 8 mm cylindrical steel object with rounded ends. This tool has been available only at the blade workshop and the inspection out in the hangar has normally been carried out using coins.

1.18.8.6 The blade workshop (Workshop Maintenance) has usually only worked with de-icer blades on special occasions, on modifications and on shipments and receipts from Eurocopter in France. De-icer blades are sent back to the factory for the replacement of leading edge strips, and the workshop's main task is the maintenance and repair of standard blades for the Super Puma and other types of helicopter. HS has approval from Eurocopter to replace the leading edge strip on standard blades and has thereby developed considerable skills on the type. This, combined with the company's considerably higher number of flying hours using standard blades, means that the company has to a great extent directed its attention towards the standard blades and the problems with which these have been connected.

1.18.8.7 The company has stated that the procedures given in MET 62.10.00.901 were not followed during the storage of main rotor blades at the company's base at Sola. Main rotor blade, S/N 617, was thus not subject to inspection in accordance with MET 62.10.00.603 when it was taken out of storage and installed on LN-OBP in October 1995.

1.18.8.8 The company has informed the AAIB/N that the company's technicians do not have their own functional description. After a debate about this, in which the trades union was also involved, it was decided to select a model in which the individual tasks, standards, rights and obligations were described in several places in the company's maintenance system.

1.18.9 Experience of using main rotor blades with de-icers on Super Puma 332 helicopters

1.18.9.1 Based on information provided from Eurocopter in January 1996, a global total of approx. 400,000 hours was logged using main rotor blades with de-icers. These are blade hours and are equivalent to approx. 100,000 hours of helicopter flying. Of these hours, HS has logged approx. 100,000 blade hours. HS was therefore clearly the largest user of this type of blade.

1.18.9.2 According to information from Eurocopter, blades with titanium leading edge strips (de-iced) were replaced because of unforeseen faults after an average of 2,450 hours of operation. The equivalent figure for 'Standard blades' was 8,400 hours. The average time between titanium leading edge strip replacements was 2,000 hours. In addition, the summary from Eurocopter showed that, of all blades which were returned to the factory, 24.7% came from HS and were sent for repair because of holes in the leading edge strip caused by erosion. The factory had not received any main rotor blades, from operators other than HS, where erosion along the leading edge strip had been the trigger for their being demounted. Returns because of holes in the leading edge strip comprised 39 blades and represented 55.7% of all blades which were returned to the factory from HS.

1.18.9.3 Eurocopter has also stated that 15 main rotor blades have been returned to the factory because of de-icer debonding. Of these, approx. 50% comprised blades in which this delamination had occurred between the leading edge strip and the de-icer element. One of these cases led to Eurocopter issuing Lettre Service No. 1205-62-94 on 22 March 1994, in which it was stressed that existing maintenance procedures should be followed precisely with regard to the inspection of main rotor blades.

1.18.9.4 The technical staff at HS have informed the AAIB/N that titanium leading edge strips have usually been replaced after 1,500-2,000 flying hours. It was stated that there had been no particular airworthiness problems with titanium blades in the company, and that the replacements of this type of blade which have been undertaken due to erosion have therefore had purely financial implications. This has led to much higher operating costs, which were accepted within the company, but which did not lead to any debate about reliability in relation to safety.

1.18.9.5 Eurocopter maintains to the AAIB/N that, at regular technical meetings, HS never raised any discussion with Eurocopter about the high rate of erosion on titanium leading edge strips. For its part, HS maintains that Eurocopter was aware of the high rate of erosion, and that this was blamed on routine operations in wet weather. The AAIB/N cannot see that either HS or Eurocopter have raised the question of the problem of high rates of erosion with the other party at any formal level. However, it has been pointed out that there was a more informal level of contact between the manufacturer and HS via the manufacturer's 'field representative' who was based at

HS's offices.

1.18.9.6 The AAIB/N has not received any information on any similar cases in which titanium leading edge strips have caused aerodynamic disturbances through parts of the strip having come loose and folding out into the air flow.

1.18.10 Operating conditions

1.18.10.1 It has not been one of the company's normal flight operations requirements to use 'titanium blades' for flights to oil installations in the North Sea. HS Super Puma helicopters have occasionally been flown using this type of blade without these having an electrical connection, or without such de-icing equipment being fitted on the helicopter. Engineering personnel at HS have stated that, on occasion, this was due to a lack of 'Standard blades'. 'Titanium blades' have also displayed better flight characteristics with a generally lower level of vibration.

1.18.10.2 The CAA/N has established standard flying altitudes for flights to oil installations. This has been done in cooperation with the helicopter companies.

Typical flying altitudes are 2,000 ft - 3,000 ft. By agreement with air traffic control, these altitudes can be departed from in specific weather conditions. In very high wind, flying is typically carried out at 1,000 ft.

1.18.11 Personal safety during helicopter transportation to offshore oil installations off the Norwegian coast

1.18.11.1 Based on the fact that, over the years, there have been several accidents involving helicopters in the North Sea basin, the AAIB/N decided in this case to look more closely at personal safety during transportation by helicopter to and from oil installations in the Norwegian sector. The AAIB/N found that there was reason to look more closely at the following subjects:

- Public authorities which have an influence on personal safety
- The rescue services in general
- HRS notification and communications
- Conditions on board the helicopter
- Requirements for survival suits for pilots and passengers
- Requirements for the use of life jackets - compatibility with survival suits
- Emergency radio beacons - requirement and use
- Communications
- 'Hostile Sea'
- Safety training
- Rescue equipment in the helicopter
- Other matters

1.18.11.2 To obtain the best possible background on these subjects, the AAIB/N has, in addition to HS, also talked to and interviewed a series of bodies and people, such as the Norwegian Petroleum Directorate, BP Norge, employee and employer organisations within the oil industry, the Rescue Coordination Centre for Southern Norway and 330 Squadron at Sola. In addition, the AAIB/N has participated in a demonstration of the use of life rafts, etc., at NUTEC in Bergen.

1.18.11.3 In 1996, the Norwegian Ministry of Justice and the Police established a committee to re-evaluate the rescue helicopter service. The committee published its recommendations in the Report on the Rescue Helicopter Service (*Utredning om redningshelikoptertjenesten*) on 12 December 1996.

1.18.12 The employer and employee organisations in the oil industry

During this investigation, the AAIB/N has also talked with representatives of the employers' organisation - Oljeindustriens Landsforening - (OLF) [Oil Industry National Association] and the employee organisations - Oljearbeidernes Fellessammenslutning - (OFS) [The Federation of Oil Workers Trade Unions]/Norsk Olje og Petrokjemisk Fagforbund - (NOPEF) [Norwegian Oil-and Petrochemical Workers Union] within the oil industry. At these meetings, the safety of helicopter passengers was discussed in relation to personal equipment and training.

The following summarises the conversations with the respective organisations.

1.18.12.1 OLF

The OLF has drawn up safety arrangements for all employees who are working on installations in the North Sea. Within these arrangements, a safety course has been prepared which everyone must attend before being permitted to work in the North Sea. This course includes a general part about helicopter transportation. The reason that the oil industry found this necessary was that many people take on work in the North Sea "without ever having seen the sea". Approx. 35% of the oil workers could not swim. The Norwegian Petroleum Directorate has accepted the OLF standards for the safety courses and the individual operators must adhere to the requirements. The safety requirements also include the specification that passengers on helicopters must use survival suits which have the same requirements specifications as those used on the installations.

The opinion was expressed that more emphasis should be placed on the transmission of experience from national and international incidents/accidents in oil-related helicopter transportation.

Otherwise, emphasis was placed on the fact that it is the CAA/N which is the responsible authority as regards the transportation of people by helicopter to the oil installations in the North Sea.

1.18.12.2 OFS/NOPEF

Both organisations were still of the opinion that the situation was such that many of their members feel that it is a risk to fly out into the North Sea by helicopter, but that transportation by other methods was not very realistic. At the same time, they expressed the opinion that they had a great deal of confidence in the helicopter companies. It was also their clear opinion that not all types of helicopters were particularly passenger-friendly, and that they were military designs adopted and adapted for the civilian market. Both of the organisations stressed that the NUTEC course in Bergen, which demonstrates an underwater evacuation from a full-scale model, should be mandatory for everyone. It is currently up to the individual operator as to whether it makes use of the NUTEC course. The following issues are key points which arose out of conversations with the employee organisations:

- The basic training varies depending on where the person is employed. The best training is given to those employed in the 'primary' companies. It was regarded as preferable for training on helicopter safety (such as that at NUTEC) to be carried out with an air crew.

- Clarification about the use of the helicopter life jackets in addition to survival suits (on the safety course, people were informed that life jackets are not to be used if the suits have flotation elements). Evaluation of standard types of survival suits with inflatable flotation elements.

- Strobe lights on the suits

- Knives in the suits

- Quality control of water seepage into the suits.

- Standards of PA (Public Address) systems which were too poor. There is too great a difference between how the pilots use the PA systems for information. Headsets with wires can be dangerous.

- The employee organisations are not permitted to sit on the Council for Helicopter Safety in the North Sea (*Rådet for helikoptersikkerhet i Nordsjøen*).

- The type of clothing worn under the survival suit is crucial to the survival time in water. However, it is a fact that the warmer the clothing which the passengers wear under their suits, the poorer the level of comfort during the journey.

Usually, the passengers wear normal clothing under their suits, for example jeans and a shirt.

1.18.13 BP Norge (BPN)

1.18.13.1 BPN was the commissioning employer during this flight. This means that BP had a long-term contract with HS for the transportation of personnel to the operator's platforms in the North Sea. In addition to the aviation-related safety requirements, all passengers on board were subject to BPN requirements and safety regulations, including safety training in accordance with the OLF rules.

1.18.13.2 A short time after the accident, the AAIB/N talked with relevant people at BPN and their subcontractors, who also had personnel on board. The operator showed a great deal of interest as regards the AAIB/N investigations regarding personal safety in helicopters. In addition, after the accident, BPN set up its own working party which had a mandate to collect and report on the experience gathered by the crew and passengers during the emergency landing. The following areas were of interest:

- Survival suits
- Rafts
- Life jackets
- Procedures
- Communications
- Training

These areas will be discussed in the analysis section of this report.

1.18.14 Accident involving a Super Puma helicopter within the British sector

After a helicopter accident involving a Super Puma at the Cormorant Alpha platform in the North Sea in 1992, the UK Civil Aviation Authority (CAA) drew up a report on safety and rescue for offshore helicopter traffic: 'CAP 641 Report of the review of helicopter offshore safety and survival'. This report was prepared on the basis of recommendations in the Aircraft Accident Report 2/93 issued by the UK Aircraft Accident Investigation Board (AAIB) which investigated the accident. The CAA report concludes with 17 recommendations. These contain few radical proposals for continued helicopter traffic in the North Sea, but deal with a number of the problems arising during these operations. A possible ban on flying in weather conditions which are not suitable for ditching is highlighted, and the time factor for survival in water during any rescue of passengers and crew is studied.

The course of events during the accident at the Cormorant Alpha platform and during LN-OBP's emergency landing in the North Sea are very different. The AAIB/N has chosen to select individual examples from the report which show similarities between these two incidents. Otherwise, the AAIB/N recommends that this report is examined by all of the parties concerned in oil production operations in the Norwegian sector, by public authorities and transport companies as well as operators.

- When a helicopter develops technical problems such that they lead to an emergency landing at sea, the chance of being rescued (with or without a life raft) should be very good with the aid of a rescue service which can locate, pick up and transport those on board to a safe place.
- Controls on choice of personnel for work in the North Sea and realistic emergency training of passengers in the North Sea can best be carried out by the oil companies.
- Knowledge gained from incidents and accidents should be used in emergency training.
- The CAA/N's inspectors should formally approve all parts of the emergency training procedures for crew and passengers (briefings and videos) in order to reach a high standard.
- The UK Air Navigation Order (ANO) requires crew to wear insulated survival suits when the sea temperature is below +10°C. The way in which the crew can best be protected is discussed without any satisfactory solution being given.
- Passengers must be wearing a survival suit. These should preferably be of a design which facilitates standardised training and briefing. To be able to survive in cold water, gloves must be available in the survival suit, and these must be put on as soon as possible.
- Experience has shown that, after an emergency landing on water, the helicopter may, after a short time, capsize because of its high centre of gravity. The release of cabin doors can, on some helicopter models, only be carried out while the helicopter is floating upright on the surface. After the helicopter has turned over and is lying upside down, it is difficult to carry this out. It is therefore recommended that the cabin doors are released shortly after landing on the sea.
- It should be just as easy to use the life rafts if they are lying upside down after release and inflation.
- There is incompatibility in the simultaneous use of a survival suit and a life jacket.
- Doubts are raised as to whether the level of rescue helicopter standby is sufficient.

1.18.15 IHUMS - extended area of application

1.18.15.1 The intention behind the development of the IHUMS system is primarily maintenance-related and, to a lesser extent, determined by flight operations. This means that the parameters which are recorded in the IHUMS system are primarily used for monitoring the helicopter's technical 'state of health' on a preventive basis. For example, the development of a bearing fault in the rotor's propulsion system could be stopped at a time when the consequences of rectifying a fault would be considerable less than if the fault had been discovered by means of the traditional maintenance system.

1.18.15.2 In monitoring this technical 'state of health', a number of accelerometers fitted in different locations on the helicopter are used to signal the vibration levels. Eurocopter has indicated the possibility of being able to develop this system to record, if possible, the vibration level to which the helicopter was subject in this case when the blade error arose, and whether this could provide the pilots with meaningful information at the same time, for evaluating the extent to which continued flying would be possible.

1.18.16 The company's internal investigations in connection with the accident

After this emergency landing, the company established an investigation team of five people as a matter of routine. As with the AAIB/N, the internal team dealt with both the flight engineering aspects and situations concerning flight operations procedures, rescue equipment, evacuation and training. In its report, the internal team drew up a series of recommendations which, in the main, are also touched on by the AAIB/N in this report.

Of the technical matters, stress was placed on quality assurance in the manufacturing process and improvement to the maintenance processes. Of other matters which are mentioned, coordination of training at NUTEC and the company's procedures, requirements for grab lines on the floats, compatibility in the use of life jackets/survival suits, securing of lines/ropes on the rafts and a recommendation about landing with the wind coming in from the port side (instead of, as now, from the starboard side) for efficient use of the sea anchor.

1.19 Useful or effective investigation techniques

In this investigation, no methods have been used which merit special mention.

2 ANALYSIS

2.1 Flight operations factors

2.1.1 General

2.1.1.1 The CAA/N has in collaboration with the helicopter companies, established the relevant standard altitudes and corridors for flights to offshore oil installations. Two of the most significant background reasons for such a choice:

* Selection of favourable altitudes in relation to icing

* Forsvaret [the Norwegian defence forces] requirements for being able to monitor sea areas, while also being aware of the location of heavy helicopter traffic.

2.1.1.2 Use of rotor blades with de-icer has not normally been a requirement for flying to North Sea oil installations. Usually, most of the Super Puma helicopters fly in this type of traffic without de-ice equipment because the altitudes selected do not normally give rise to icing problems. This also means that the rotor blades are more likely to be subject to liquid impingement erosion at the selected altitudes. The reason for liquid impingement erosion being typical at such flying altitudes is that the size of water droplets in wet weather increases on moving down towards lower levels of air. The typical size of droplets at the relevant flying altitudes may be 1-2 mm, which must regarded as large droplets. In research, large droplets have been shown to have a greater erosion effect than very small droplets.

2.1.2 The flight in question

2.1.2.1 The flight began as a normal routine flight to oil installations in the North Sea. The crew preparations complied with current procedures and regulations. The flight was normal until the vibrations occurred approx. 26 minutes after departure. It was initially difficult for the crew to locate the source of the vibration. They chose Organizational and management information therefore to undertake an immediate descent with a view to possibly carrying out a controlled emergency landing at sea. After a short reassessment of the situation, at a low altitude above the surface of the sea, the crew decided to perform the landing. The AAIB/N is of the opinion that this was the correct action to take.

2.1.2.2 The briefing which was given to the passengers before the descent was not completely in accordance with the emergency checklist: a matter which should be evaluated by the company. Otherwise, the company's internal investigation team has pointed out other situations which could also be improved, such as that regarding the coordination of training with NUTEC in Bergen and the distribution of tasks between the pilots when using emergency procedures.

2.2 The cause of vibrations occurring in the helicopter prior to the emergency landing

2.2.1 It can be confirmed that the vibrations which the crew and passengers experienced before the emergency landing, resulted from a fold of the leading edge strip on main rotor blade S/N 617 folding over and projecting out into the flow of air. This did not lead to an imbalance because of any displacement of weight, but to disturbances in the air flow around the blade tip because of the fold, leading to an aerodynamic imbalance and vibrations coinciding with the number of revolutions of the main rotor. Aerodynamic imbalance would be dependent on the load on the rotor system. This would explain why the crew noticed a reduction in the vibrations during the descent and a considerable increase in the intensity of the vibrations when they hovered before the helicopter landed on the sea.

2.2.2 There is reason to believe that the fold projected into the air flow and stabilised itself in a short space of time. After the cracks had weakened the leading edge strip sufficiently for the fold to occur, the fold stabilised itself rapidly in a position in which aerodynamic forces became balanced against the centrifugal force. This is substantiated by the crew having noticed that the vibrations started suddenly.

2.3 Mechanisms causing a fold of the leading edge strip to lift away from the base layer

2.3.1 The AAIB/N is of the opinion that the fold of the leading edge strip lifted away from the base layer as a result of aerodynamic forces exceeding the limit for the mechanical loading which the strip was able to withstand. At this time, the outer part of the leading edge strip was weakened by three factors:

- As a result of factors such as erosion, a longitudinal crack of 285 mm which started at the zero line and which had several transverse cracks.
- Lack of bonding to the base layer.
- A modification which weakened the strip's strength at the tip had removed a fixing lug and had left tool marks which developed cracks radiating from the corners of the cut-out section.

(These three factors are analysed in more detail under points 2.3.3, 2.3.4 and 2.3.5.)

As a result of this, the fold was only held in place by a 55 mm long section between a transverse crack radiating from the main crack and a crack coming from the rear corner of the cut-out section (see Figure 17).

2.3.2 Calculations performed by DNV show that the bending factor which would have to exist for the fold to occur would be equivalent to a surface pressure of 3.2-3.6 kg/cm^2. This is a surface pressure which could not arise because of stagnation pressure at subsonic speeds, and which could therefore not arise at the tip of the main rotor blade. The AAIB/N is of the opinion that a force sufficient to cause the fold could nevertheless have arisen if the loading had increased as a result of oscillation and resonance.

2.3.3 Erosion along the leading edge of the strip

2.3.3.1 Examinations carried out along the leading edge strip on main rotor blade S/N 617 (cf. 1.16.4) showed that large parts of the strip's material at the tip were missing as a result of erosion. Furthermore, it has been ascertained that this is due to droplet erosion, Liquid Impingement Erosion. The AAIB/N is of the opinion that this erosion could be explained by the pattern of operations at HS with a lot of flying taking place in rain and damp weather. This would mean that, for a large part of the time, the leading edge strip would be exposed to a series of collisions with water droplets at high speed.

2.3.3.2 In the eroded area, a series of small cracks had appeared (see Figures 41A- 42B). These cracks then became interlinked and created the main crack shown in Figure 17. There is therefore a clear link between the creation of the main crack and the pattern of erosion on the leading edge strip. In the same way, the transverse cracks began in the area in which there was major erosion, but several of these extended into parts of the strip not been affected by erosion.

2.3.3.3 Based on information supplied by HS and Eurocopter, the AAIB/N believes that the erosion on main rotor blade S/N 617 was normal or a little more than might be expected with an operating time of 1,590 hours. The AAIB/N found no evidence to indicate that the leading edge strip was subject to abnormal loading or abnormal erosion in the period just before the accident.

2.3.3.4 The AAIB/N cannot determine the exact status of the leading edge strip with regard to erosion and cracks, when the last PFC was completed at 05.00 hours on the morning before departure. However, there is reason to believe that the leading edge strip was holed by erosion and cracks. The AAIB/N believes that a visual inspection at close range would have been sufficient to disclose this, but considers it less probable that this could have been discovered from ground level.

2.3.4 Deficient bonding with the base layer

2.3.4.1 A total of 39 main rotor blades with titanium leading edge strips have been returned to Eurocopter, having developed holes resulting from erosion. None of these had any loose folds on the leading edge strip. Nor did main rotor blades S/N 733, 811 and 905, which were examined at HS premises, have any visible cracks or loose folds. This is despite main rotor blade S/N 905 having considerably greater damage than S/N 617 caused by erosion. This underlines the fact that erosion alone is not sufficient to cause the fold to come loose, but that poor bonding is also a contributory factor.

2.3.4.2 In its report, DNV establishes that a large proportion of the cracks in the leading edge strip contain fatigue fractures. Fatigue fractures are created through the effect of load cycles. These load cycles are caused mainly by the variation of the airspeed affecting the rotor blade, depending on whether the blade is moving backwards or forwards in relation to the direction of flight. The AAIB/N is of the opinion that these variations in speed will affect a loose leading edge strip much more powerfully than an equivalent strip which is held fast by vulcanisation to the base layer. In the opinion of the AAIB/N, this indicates that the fold had been loose for a period of time and was, at the same time, affected by normal changes in loading. Together with erosion damage and the modification, this led to the formation of cracks on the leading edge strip. Calculations made by DNV regarding that one of the transverse cracks had existed for 86 min. must only be regarded as an estimate, but the AAIB/N believes that the cracks originated some time before the departure prior to the accident.

2.3.4.3 The AAIB/N believes that the considerable areas of the leading edge strip which had come loose from the blade can, to all intents and purposes, be blamed on conditions prior to the accident. This is substantiated by the following argument:

Water was not forced into the honeycomb core of the main rotor blade when the helicopter was floating upside down in the water because the blade was undamaged and watertight. When the helicopter sank, it took a relatively short time to descend to a depth of 285 m. The water pressure on the skin of the main rotor blades increased so rapidly that the honeycomb core was subject to a pressure which led to a flattening of large parts of the blade. This also led to the blade's leading edge being crushed, or to the blade's core coming loose from the leading edge (see Figures 11A and 14A). This subjected the leading edge and leading edge strip of the blade to a pressure which gradually diminished as the water flowed into the core of the blade and equalised the pressure. However, this flexure led to the leading edge strip loosening from the upper side of the de-icer element for a length of 223 cm. This substantiates the fact that the large delaminated surface along the upper side of the blade cannot be a result of more than one week's effects of sea water. Nor does the AAIB/N believe that the 17 hours during which the helicopter was floating upside down in salt water affected the vulcanisation to any considerable extent. An attack on the vulcanisation by salt water, as indicated by Eurocopter, should have led to a gradual delamination in those places where there was first contact with water, before spreading further inwards. The pattern drawn on Figure 18 does not indicate that this was the case.

2.3.4.4 The areas of the blade which proved, after the salvage operation, to be delaminated, do not appear to be demonstrably different with regard to their nature or fault mechanisms. The AAIB/N therefore believes that it must be the same mechanism which triggered the delamination. However, the AAIB/N has not been successful in discovering which fault mechanism caused this. Since it has not been possible to discover anything ‘unusual’ in the history of the blade, the AAIB/N believes that the delamination was not caused by the ‘use’ of the blade, but that the fault arose during the production and replacement process in 1991.

2.3.4.5 The AAIB/N’s overall impression is that, prior to the accident, there were considerable areas of the leading edge strip on main rotor blade S/N 617 which were greatly weakened or were not bonded with the base layer. Such an area at the tip of the blade affected the development of the pattern of cracks on the leading edge strip and was a precondition for the fold being raised from the base layer and projecting into the air flow. After the salvage activities, it was discovered that the remaining areas with weakened or missing bonding lacked any bonding at all to the base layer.

2.3.5 The modification

2.3.5.1 In the opinion of the AAIB/N, the Eurocopter Technical Instruction No. 230 modification weakened the leading edge strip in the area adjacent to the zero line. This weakening was caused by the following factors.

- A fixing lug on the leading edge strip was removed.
- The rectangular excision on the leading edge strip reduced the structural integrity of the strip and formed the fold which later bent along a crease and became raised into the air current.
- The rectangular excision left behind corners with a small radius and tool marks which permitted cracks to form.

2.3.5.2 The AAIB/N believes the design of the modification was, in this way, contributory to the fold coming loose and bending over at the time in question. A leading edge strip without modification would have tolerated the overall loading situation much better. The possibility of discovering erosion holes in the leading edge before this had serious consequences would then have been greater.

2.4 Eurocopter's role in the design, manufacture and maintenance of the main rotor blade in question

2.4.1 According to Eurocopter, titanium leading edge strips on main rotor blades have an average life of 2,000 operating hours. Equivalent figures from HS indicate that the leading edge strip had to be replaced after 1,500-2,000 operating hours. These changes were mainly caused by erosion in the leading edge strip. This might mean that, during the course of its total expected operating life, a main rotor blade would have to have its leading edge strip replaced between 9 and 13 times. On this basis, the AAIB/N finds there is reason to question how well-suited unalloyed titanium is as a material for leading edge strips on main rotor blades which are subject to liquid impingement erosion. A question must also be raised as to the use of such materials, when it can be shown that the loads to which the material is subjected by the droplets at normal flying and rotor speeds, are within the range of the material's limit of tolerance.

2.4.2 The production process for the blade's de-icer element contains a number of critical points which could be indicative of whether this would produce the best possible result (cf. 1.16.1.6). The process therefore sets strict requirements for accuracy and quality control. This applies both to implementation and use of materials. The AAIB/N did not assess the production process in 1991, but understands that improvements have been made in the period up to 1996. The investigation work on the leading edge strip, however, indicates that the 'tapping' inspection does not reveal all forms of delamination between the leading edge strip and the de-icer element below (cf. 1.16.3.3). The AAIB/N is therefore not able to discount the fact that errors in vulcanisation may have passed the 'tapping' inspection carried out in the production process, without having been discovered. On the basis of a collective evaluation of the available information, the AAIB/N is of the opinion that there are persuasive reasons for asserting that it must be possible to trace the delamination which has been discovered on blade S7N 617, back to the production and replacement process which was used in 1991 (ref. 2.3.4.4).

2.4.3 When the examination of the blade was begun, it was not then known to the AAIB/N which mechanism had led to the high rate of erosion along the leading edge. Neither Eurocopter nor HS provided any information on whether the high rate of erosion was a known phenomenon and that this was due to extended periods of flying in the rain. Subsequently, both parties gave the impression that this was a known problem. The AAIB/N cannot see that either HS or Eurocopter have, at any formal level, taken up the question of the high rate of erosion with the other party. Informal contact concerning the problem is supposed to have implied that Eurocopter took a negative attitude to design changes because of the financial consequences these would have implied.

The AAIB/N is of the opinion that the company should have contacted Eurocopter more formally, regarding the consequences of liquid impingement erosion. In the opinion of the AAIB/N, such formalisation would have created the basis for improvements in blade design and initiated a reassessment of the maintenance programme in view of the climatic conditions under which HS operates.

2.4.4 In the Eurocopter maintenance programme for daily inspections (B.F.F., T.A., and A.L.F), no requirements are specified for inspecting the leading edge strip at close quarters (cf. 1.18.6.1 - 1.18.6.4). In the opinion of the AAIB/N, the description of blade inspection carried out from stations 3 and 5, does not provide any opportunity for discovering small holes and minor damage in the leading edge strip at the tip of the blade. Nor does the height of the main rotor provide the opportunity for making a thorough inspection of the area from the ground. The requirement that the main rotor blades are to be washed every 25 hours when flying in operating conditions involving high atmospheric salt content, necessarily requires close proximity with the blade, but this work does not need to be carried out by technically skilled personnel. A thorough inspection undertaken by qualified personnel is therefore assumed to be carried out every 500 flying hours. (This depends on the helicopter flying 500 hours in less than 18 months.) If no doubts arise, no damage is discovered or no other work has to be carried out in the area, there is a risk that a main rotor blade may only be subject to a thorough inspection in the relevant area 3 or 4 times during the lifetime of the leading edge strip. In the AAIB/N's opinion, this does not provide a sufficient guarantee that delamination, holing and cracking in the leading edge strip will be discovered in time.

2.4.5 The AAIB/N is of the opinion that the maintenance programme reflects the fact that Eurocopter did not foresee, to any great extent, that the leading edge strip could create aerodynamic disturbances if parts of it were to come loose. To a significant degree, the factory focused on the leading edge strip as protection for the underlying de-icer element and not as the origin of possible aerodynamic problems. Primarily, delamination of the leading edge strip is undesirable because this would lead to a reduction in heat transfer from the de-icer elements to the blade's surface. As a result, this has placed limitations on the criteria given in MET 62.10.00.603 (see Appendix 2).

2.4.5.1 In the AAIB/N's opinion, a maintenance programme containing clear criteria for the size of areas which can become delaminated shows that Eurocopter clearly knew that delamination on the leading edge strip could represent a problem. The fact that Eurocopter received blades for repair because of delamination between the leading edge strip and the de-icer element underlines this. The AAIB/N believes that this ought to have led to a higher level of vigilance on the part of the factory as regards the safety risk which could be caused by unsuitable delamination.

2.4.5.2 The AAIB/N believes that the method of detecting delamination (bonding checks by tapping) has a weakness in that it mainly detects delamination in places where there is a lack of contact between the layers. The method did not detect the fact that the samples (cf. 1.16.3.3) had become delaminated and the AAIB/N believes that this could be a contributory cause of the non-detection of 'poor' or 'deficient' bonding, during the inspection carried out by HS on main rotor blade S/N 617, 38 flying hours prior to the emergency.

2.4.5.3 The AAIB/N believes that, while drawing up Eurocopter Technical Instruction No. 230, Eurocopter did not pay sufficient attention to the weakness which the modification implied for the leading edge strip. In the AAIB/N's view, one possible scenario combined with two unfavourable factors, i.e. maximum permissible erosion and delamination on the leading edge of the strip, would be realistic, if viewed on the basis of the fact that the factory had received main rotor blades for repair because of both erosion and delamination. Such an option should therefore have been assessed while drawing up the modification.

2.5 Maintenance at HS

2.5.1 <u>The performance of maintenance on main rotor blade S/N 617 at HS</u>

2.5.1.1 The AAIB/N considers that there is no reason to doubt that the last two inspections of the helicopter, before the accident, were carried out conscientiously. According to those involved, the inspections were carried out in accordance with proven procedures and the applicable maintenance data. The inspections were performed from a position at the rotor head and from ground level. The AAIB/N believes that the damage, which by this time had probably already occurred on the main rotor blade S/N 617, was not visible from the inspection positions, but that it could easily have been discovered if the blade had been inspected at close quarters. On the DMC checklist drawn up by HS, the abbreviation GVI has been used (cf. 1.18.7.3). The definition of this abbreviation, as given in the MOM, describes an inspection which specifies requirements for possible physical contact with the object being checked. However, the requirement is not absolute, since the expressions 'as required' and 'when necessary' are used in the instructions. The AAIB/N questions the use of GVI in the DMC checklist while using the 'Expanded Check List' MET 05.21.00.603 and MET 05.21.00.604 as reference material. These references only cover inspections undertaken from stations 3 and 5. This does not give sufficient conformity between the checklist and the information which forms the basis for the checklist. Nevertheless, the AAIB/N is left with the impression that the company technicians endeavoured to achieve a certain amount of close contact with the blades during the inspection, but that this was carried out on an individual basis with no special arrangements on the company's part.

2.5.1.2 According to information provided by the company, the main rotor blades on LN-OBP were inspected in accordance with MET 62.10.00.603 a total of three times during the course of the last 260 hours. The last inspection of main rotor blade S/N 617 was carried out 38 hours prior to the emergency landing. The three inspections were completed without special remarks. This might be explained by the blade having no delamination under the leading edge strip on these occasions, or by the inspections performed not having revealed any defects or delamination. During the investigation of the main rotor blade in question, the AAIB/N gained a good deal of experience in using the tapping inspection method as described in MET 62.10.00.603. In particular, the opportunity to verify the results provided good information about the method. The AAIB/N believes that the type of tapping tool was of no conclusive significance to the result of the investigation, but that it was significant that a certain degree of skill could be built up. The results which the AAIB/N gained during the examinations of main rotor blade S/N 617 indicate that the tapping inspection does not reveal all forms of delamination between the leading edge strip and the underlying de-icer element (cf. 1.16.3.3). The AAIB/N believes that the helicopter could not have flown for many hours with up to 50% of the leading edge strip on the relevant main rotor blade having come loose prior to the emergency landing (see Figure 18). It appears, therefore, that areas of greatly weakened vulcanisation existed prior to the accident. These areas then became so loose as a result of the stresses after the emergency landing, that a pattern of bonding and no bonding arose. The obvious assumption, therefore, is that areas such as these, with greatly weakened vulcanisation, would not have been discovered by inspections using the tapping method.

2.5.2 Erosion damage to main rotor blade S/N 905

The erosion damage to main rotor blade S/N 905 can only be explained by this blade having had an abnormally high rate of erosion or by existing holes in the leading edge strip having been overlooked on previous inspections. Both alternatives give cause for concern, in the AAIB/N's opinion. There is therefore reason to question why the erosion damage on this blade did not trigger an examination at an earlier stage, and not, as in this case, after LN-OBP had been involved in the accident.

2.5.3 The company's maintenance arrangements

2.5.3.1 The company's system of technical manuals, and particularly the master documents, describes the processes which tackle the establishment of basic maintenance data and the performance of maintenance within the company. On the basis of quotations reproduced in 1.18.3 and 1.18.4, the AAIB/N questions the degree to which the company has been following its own guidelines and stated intentions. In this section, the AAIB/N therefore wants to assess, in more detail, some elements of the master documentation which the Commission believes are of significance to the development of technical aircraft maintenance in the company.

2.5.3.2 In MOM 06-01-05, it is stated that maintenance must "retain the reliability and performance specifications that are built into equipment during design, manufacture and modification". The AAIB/N is not aware that HS has questioned what might be expected to happen as regards main rotor blades with titanium leading edge strips. As a result, it would be difficult for the maintenance system to sustain a level of reliability which is unknown. In a comment from the hearing, HS states that they are using recognised principles for reliability monitoring included in a document from the UK Civil Aviation Authority (CAA) about Condition Monitored Maintenance. As a result, HS believes that they are fully in control of the level of reliability which may be expected as regards rotor blades with titanium leading edges. It is further maintained that design reliability is defined by the company as "that which the operator considers to be the reliability of new materiel after it has been brought into normal operations". The AAIB/N does not wholeheartedly share this understanding. The pattern of operations and therefore the load to which the titanium leading edges are subject in the wet weather flying which is typical for HS, has been shown to be on the borderline for the particular material used in the leading edge strip. Such a condition does not appear to be included in the basic data for 'design reliability'. Another situation related to reliability technology is that the technology permits adjustments to the maintenance intervals. The AAIB/N cannot see that HS has applied reliability technology which have implied changes to the maintenance procedures or intervals, or which have in some other way taken care of the problem with mechanics which is present in liquid impingement erosion on titanium blades.

2.5.3.3 Furthermore, it is interesting to note that HS holds up the use of terotechnology in MOM 06-00-20 as a controlling factor in maintenance. It is the AAIB/N's understanding that this means that all elements which affect the life cycle costs of a product must be managed to attain the best possible result. One of the prominent features mentioned in the literature concerning terotechnology is that the design process plays an absolutely crucial role. Generally speaking, it the task of the designer to try to 'design out' maintenance and 'design in' operational reliability. However, it is not just during the design phase that the designer is a crucial figure. During the entire life cycle of a product, the decisive factor is that there should be an ongoing and constructive flow of information between the design level, production level, maintenance and other key functions, so that the 'terotechnology cycle' is completed. The AAIB/N believes that it can be particularly demanding to execute the principles of terotechnology in aviation because the 'terotechnological cycle' is not completed within their own organisation. Because of this, several players will be dependent on one another within a system in which the same objectives cannot always be combined. HS maintains that they are the player within the 'cycle', which is carrying out its defined role in feedback to the manufacturer. In the opinion of the AAIB/N, there is no evidence that the company's experience of operational safety/operational economy of blades with titanium leading edges, have implied changes to the design or maintenance. It is difficult for the AAIB/N to discern whether the principles of terotechnology have been applied in practice with regard to main rotor blades with leading edges made of titanium, and the significance which such principles should have had, in such case. In the AAIB/N's opinion, it is also difficult to see how such a technique could control maintenance when the company itself states that there is no precise definition of the term, even in the standards or regulations. The AAIB/N believes that the company should have defined the terotechnology principle by using a recognised definition/standard and by having given an account of this in its manuals. In the UK, the Committee for Terotechnology, appointed by the UK Ministry of Technology established just such a definition in 1975.

2.5.3.4 In the company's MOM 06-00-20 (cf. programme rules in 1.18.2.3), it has been established as a requirement that the maintenance programme must contain only "items that satisfy MSG-3 Applicability and Effectiveness Criteria". The content of these criteria includes elements of both safety and economic assessment. If, for example, the safety criterion under the work task of "Inspection" in the MSG-3 Planning document is considered, it is established that the work task must "reduce the risk of failure to assure safe operations", in other words it must control safety. Criteria from MSG-3 must therefore form requirements for all sub-elements in the maintenance programme. Whether such requirements really are to apply, becomes more uncertain on reading PMTD 01-10, in the opinion of AAIB/N. It has been established, on the basis of information from the factory that the basic maintenance of main rotor blades of the type in question, was not based on a process using MSG-2/3 or equivalent as a basis. Neither can it be discerned that any equivalent process has otherwise been used at a later date. Therefore, in the opinion of AAIB/N, there is too great a difference between the requirement in MOM 06-00-20 and the actual basic data which may be used for determining the maintenance of rotor blades with titanium leading edges.

2.5.3.5 The company states that it is responsible for developing a maintenance programme which takes care of the reliability designed into the helicopters. It also maintains that the ongoing maintenance of rotor blades of the type in question is based on the criteria for On Condition (OC) maintenance. In the PMTD (cf. 1.18.3.3), the company has defined criteria for this maintenance process. In the AAIB/N's opinion, the company has not adhered to its own standards as established in the PMTD, concerning OC maintenance. This maintenance procedure is based on the fact that an inspection should be able to prove airworthiness (safe operation) until the next periodic inspection is carried out on the same area, and that it should be possible to compare the last physical and recorded status, with the status recorded during the previous inspection. In other words, the development of a fault should be observable in good time before a fault occurs. These principles are therefore established in the procedures manual mentioned. It has been the experience of HS, that titanium leading edge strips must be replaced after 1,500 to 2,000 hours of operation. This means that a detailed inspection of the leading edge strip will be carried out 3 or 4 times during the course of this operating period, provided that no special problems occur or that the maintenance programme is affected by other factors. On the basis of the experience available, AAIB/N believes that such an inspection frequency would not be in accordance with the principles on which OC maintenance is based.

2.5.3.6 In MOM 06-01-05 (cf. 1.18.3.3), it is asserted that the maintenance programme, documented in the MRM, was developed on the basis of a 'logical method', where failure modes and the effect which such errors might have on safety and finance should be detected, without any reservation as regards exceptions to the rule. It has also been established in MRM 00-01-00 that "together with the operational environment and experience, forms the basis for the issue and development of preventive maintenance program documented in this MRM". The AAIB/N believes that, in such statements, the company appears to have built in conditions for taking account of the company's defined maintenance level without this apparently being expressed in the maintenance programme.

HS has expressed the opinion that neither the company nor the manufacturer has regarded the titanium leading edges as a safety problem. The company states that the blade type, on the other hand, has demonstrated a higher level of safety in relation to blades with segmented steel leading edges. Since the company has experience of both delamination and erosion on titanium blades, it would not have been unreasonable for the company to have undertaken a risk assessment of such combinations, particularly because the maintenance programme should be developed using methods which disclose failure modes and the effect which this might have on safety. In this context, it might be pointed out that the company has put emphasis on the fact that safety work is an ongoing process of improvement and that this must be integrated into the daily work of all departments.

2.5.3.7 On the basis of the assessments above, the AAIB/N is of the opinion that HS has not made use of its operational experience and its own maintenance conditions for developing a maintenance programme for titanium blades which has been sufficiently satisfactory to take into account of possible failures which might destroy the assumed level of design applicable to this type of blade.

2.5.3.8 In the AAIB/N's opinion, the fact that the company's technicians do not have their own functional description places high demands on the general view and accessibility of the company's system of manuals. Similarly, this places great responsibility on the company regarding updating, follow-up training and introduction into the company's procedures. The AAIB/N believes that the company's comprehensive and, in part, heavily specialised manuals system might be an obstacle to individual technicians gaining familiarity with, and a good understanding of these procedures.

2.5.3.9 The company's technicians were not completely familiar with the modification carried out (ref. 2.3.5.1) on the leading edge strip. The company's engineering management has declared that it was considered unnecessary to inform the technicians about the modification since it had no significanse for maintenance or maintenance management. The AIBB/N does not share this opinion and believes that the staff responsible for completing certificates of airworthiness should, in principle, be informed of every modification. In the opinion of the AAIB/N, the company's engineering management should discuss this with the technicians union within the company.

2.5.4 Monitoring reliability

2.5.4.1 In its manuals, HS describes a comprehensive system of controls based on the principles of quality engineering laid down in the company's Quality Manual and in the quality assurance systems which are described for the respective departments. It seems to the AAIB/N that several methods are being used for monitoring the maintenance system at HS. It is difficult to see if provision has been made for exceptions to the monitoring principles which are referred to in the HFK and PMTD. In other words, if it is an overall requirement that maintenance "must follow the principles of Reliability Centred Maintenance", together with a series of other requirements which have been discussed above, it might be assumed by the AAIB/N that the maintenance of titanium blades is also included within the principles for reliability monitoring.

2.5.4.2 It is the AAIB/N's understanding from introductory investigations, that titanium blades have not been subject to any attention with regard to the principles of monitoring mentioned above. It was confirmed from many quarters within the company that there was no reason to monitor titanium blades to any greater extent than other blades. The fact that the rate of replacement as a result of erosion on leading edge strips had been considerably higher for titanium blades than for steel blades was recognised only as a financial consequence and not as a safety problem. The company maintains that the situation regarding the reliability of titanium blades was taken up on an informal basis with the manufacturer on a few occasions.

Eurocopter is supposed to have assumed a negative position on design changes for financial reasons. In a situation like this, in the AAIB/N's opinion, the company must therefore have known that safety had to be taken care of by maintenance and not by design changes. The fact that the company did not do anything about a situation like this, as they maintain, is regarded by AAIB/N as hardly satisfactory.

2.5.4.3 A comment from the company during the hearings process, expresses the fact that titanium blades were given normal attention in the Maintenance Review Board (MRB). The company also maintains on the one hand that the wear and tear on titanium blades was not defined as any kind of safety problem. On the other hand, the company maintains that titanium blades were given normal treatment in the MRB. Since the company has maintained that wear and tear on the titanium blades was not a safety problem, such a conclusion must therefore have come from the MRB, or must have been based in some other way on the assessment from the MRB. The AAIB/N questions whether this was the best assessment, since it has been shown that the treatment of the blade in the MRB did not give rise to any changes as regards maintenance.

2.5.5 The company's overall coordination of the manuals system

2.5.5.1 It is the AAIB/N's understanding that, in aviation companies, there is often a lack of coordination in the company's system of manuals. In other words, the content of one manual does not necessarily fully agree with other internal manuals. This is partly because the manuals are often written by different authors and belong to various departments/sections. Furthermore, a series of examples can be found showing that errors in the text have not been corrected because it has not been subject to any kind of critical review. Too often, it appears that such exceptions are not discovered in the quality audits. In other inspections, the AAIB/N has discovered clear deviations in the manuals system which are of significance to safety. Since the manuals system is supposed to mirror the company's theoretical safety level, an evaluation of the standard of the manuals would be a natural part of the investigations carried out by the AAIB/N. It would therefore also seem natural for the AAIB/N to focus on the system of manuals in this investigation.

In sections 1.18.3, 1.18.4, 2.5.3 and 2.5.4 of this report, the AAIB/N has pointed out features in the company's manuals system which might be both unclear and, in certain cases, incorrect. In addition to the comments given in 2.5.3, the following should be mentioned (cf. 1.18.4):

- The expression 'delegation of responsibility' is, in the AAIB/N's opinion, fundamentally, organisationally erroneous.
- The fact that the term 'Quality' can be defined as "the result of an activity in the condition in which it was originally intended to be", seems to the AAIB/N to be both a new method of defining the term and of doubtful accuracy.

- The fact that the Quality Assurance Manager has been delegated overall responsibility for the company's quality system cannot be correct.
- The fact that "QA takes it for granted that we should view the next link in the production process as our customers" might appear to be an unclear formulation. The fact that a quality unit might take something in the organisation for granted is in itself unreasonable, but it would be worse if this 'obviousness' (customer-supplier) were not given particular emphasis in the same documentation. In such a case, the company must be able to demonstrate how the internal link in the customer-supplier relationship is clearly described as a quality tool.

The above are only a few examples from the company's system of technical manuals which demonstrate that text exists which ought to have been subject to a more critical review and possible revision.

2.5.5.2 Such a comprehensive system of manuals as the HS system, places great demands on the organisation. On the basis of the investigations which the AAIB/N has made into this matter, it should have been possible to establish that the company would have benefited from undertaking a critical review of the system of manuals, as regards both text and coordination. The company ought also to evaluate where and how the responsibility for text and coordination should be administered and monitored.

2.6 CAA/N approvals and inspections

2.6.1 As mentioned and commented on previously, Helikopter Service AS has established a comprehensive system of manuals. In the AAIB/N's opinion, this might initially be regarded as professional. However, in the AAIB/N's experience from previous investigations, manuals may have a tendency to become somewhat too ambitious, and to contain features which go beyond anything which the companies themselves would have need of in their daily operations. This also appears to apply to HS. As mentioned in 2.5.5, in particular cases, the overall coordination of the manuals' content could also be questioned.

2.6.2 In this report, the AAIB/N has pointed out several features of the HS system of manuals which could have been effective in discovering the developing fault on the main rotor blade in question on LN-OBP. The CAA/N has approved the company's collective system of manuals. The AAIB/N understands that the CAA/N has approved the content of the manuals not in detail, but rather as a system of manuals. However, in the AAIB/N's opinion, there is reason to maintain that the CAA/N should have devoted more attention during its ongoing inspection of activities, to the fundamental maintenance-related situations which are of significance in maintenance management and which are described in the company's documentation. This refers to situations indicated in particular by the AAIB/N in subsections 2.5.3 and 2.5.4 of this report. In the AAIB/N's opinion, the CAA/N should become so well acquainted with the content of the manuals that they could be included in the continuous evaluation of the maintenance inspection process, and that all manuals which have a bearing on safety should therefore be examined at regular intervals.

2.7 Summary of the aviation engineering analysis in 2.2-2.5

2.7.1 The AAIB/N has established with certainty that a loose fold of the leading edge strip on main rotor blade S/N 617 led to vibrations occurring in the helicopter, something which then led to the decision to make an emergency landing at sea. The fold became loose because of three factors which, in combination, represented a direct threat to aircraft safety, and which thereby prompted the emergency landing with the subsequent accident to, and loss of the helicopter. This state of affairs appears to have been the result of an isolated incident. It is a difficult, but not impossible, process to construct safety barriers against isolated incidents which result from combinations of errors with a varying degree of probability. The AAIB/N believes that there can be no guarantee that similar circumstances would not arise again, without an ongoing critical evaluation of the production process and improvement of maintenance procedures for the main rotor blade in question.

2.7.2 The production process for the blade's de-icer element contains a series of critical points which are crucial for producing an optimum result. On the basis of the presentation given to the AAIB/N at the Paulstra facility in autumn 1996, the AAIB/N has no reason to criticise the demonstrated production process as regards the vulcanisation of the de-icer element to the leading edge strip. However, the process places heavy demands on accuracy and quality control. Faults may therefore arise if there is no continuous effort towards the optimisation and improvement of the process, which, according to the impression gained by the AAIB/N, is being taken seriously by both Eurocopter and Paulstra. However, on the basis of the overall evaluation of accessible information, the AAIB/N believes that there are major reasons to maintain that the delamination discovered on blade S/N 617 could be traced back to the production and replacement processes as applied in 1991 (cf. 2.3.4.4).

2.7.3 The AAIB/N believes that the main rotor blades in question, with titanium leading edge strips, are not really suited to typical operating conditions in the North Sea. This has led to a high rate of replacement of leading edge strips as a result of erosion. The AAIB/N believes that the manufacturer has not exploited the potential in the available information for undertaking risk analyses during the development and revision of the blade's maintenance programme, and in evaluations prior to drawing up Eurocopter Technical Instruction No. 230. The accident was instrumental in showing that this maintenance programme, which had been developed by Eurocopter, was not sufficient to disclose the three decisive factors which together had directly influenced the helicopter's safety.

2.7.4 The AAIB/N finds no reason to criticise the maintenance work which was carried out on main rotor blade S/N 617 by HS technical staff, and which was based on the company's current maintenance data. At the same time, it may be established that the company's maintenance programme, based on that of the manufacturer (Eurocopter), does not have the built-in capability to detect the development of the precise faults which occurred in this case. A review of the manuals system at HS shows that these manuals contain descriptions of processes and practices which, if they had been used more extensively, would have provided considerable potential for improvement of the maintenance programme. In the AAIB/N's opinion, utilising the systems which HS already maintains that it does use, would have led to a critical review of the maintenance situation of the titanium blades within the company, and would have focused on safety and not just economics.

2.8 Personal safety during helicopter transportation to offshore oil installations

2.8.1 Public accountability - who decides what?

2.8.1.1 During the course of the investigation concerning this accident, the AAIB/N has gained an insight into the number of bodies which, in one way or another, either regulate operations in the North Sea petroleum industry or are significant to operations in some other way. The following summary can be made:

- Civil aviation using helicopters is regulated by means of the Norwegian Civil Aviation Act (*Luftfartsloven*), Royal Decree dated 8.1.1961, ministerial decision from the Norwegian Ministry of Transport and Communication, regulations established by the CAA/N, the helicopter companies' operations manuals and manuals for the air traffic control service. The CAA/N regulations must reflect the international standards to which Norway is obliged to adhere.
- Legislation and regulations which control oil industry activities are covered by the Norwegian Petroleum Act (the Norwegian Petroleum Directorate), the Norwegian Work Environment Act (*Arbeidsmiljøloven*) and the Norwegian Pollution Act (*Forurensingsloven*) (Norwegian Ministry of the Environment).
- Flights involving the Air Force rescue helicopters are regulated by the Norwegian Ministry of Defence, while medical crews are subject to regulations drawn up by the Norwegian Ministry for Health and Social Affairs.
- Rescue operations are regulated by means of legislation and regulations from the Norwegian Ministry of Justice and the Police.
- The Norwegian Directorate of Shipping and Navigation approves maritime equipment, including survival suits.
- Statens Teleforvaltning [the Norwegian National Telecommunications Administration] approves radio equipment in aircraft, including emergency radio locator transmitters (ELT).

In addition, there are regulations established by the oil industry.

2.8.1.2 There is therefore a large number of bodies/organisations which influence employee safety in the offshore oil industry off the coast of Norway. To a certain extent, this also applies to the approx. 400,000 passengers who are transported annually by helicopter to and from oil installations. When so many authorities are involved, grey areas can quickly arise in which there is a lack of clarity on which body is accountable. A similar situation in the UK sector of the North Sea is discussed in 'CAP 641: Report of the review of helicopter offshore safety and survival' (cf. 1.18.14).

One example of how the various regulations affect a situation for passengers is that the CAA/N requires that there should be life jackets on all aircraft. A printed instruction sheet does exist in the aircraft (called 'For Your Safety') about when and how these are to be used. It is difficult, impractical and basically unnecessary for passengers to put these on when they are already dressed in survival suits with 'lungs'. Survival suits for passengers travelling on helicopters are mandatory in the oil industry. Another example is that the standby time for the rescue helicopters must be viewed in relation to requirements on the type of clothing and which other aids may be required so that a casualty can be rescued within an acceptable time. These conditions are also controlled by different bodies.

2.8.1.3 The AAIB/N is familiar with the fact that the European aviation organisation, JAA, has appointed a working party which is evaluating safety in helicopter operations. In the AAIB/N's opinion, however, there is good reason for all of the authorities involved, not just the aviation authorities, to join together to look at safety as a whole during the transportation of people to and from offshore installations off the coast of Norway. By this, the AAIB/N means everything from the training of passengers and crew, through to clothing and the public rescue service.

2.8.2 The rescue service

2.8.2.1 As previously mentioned in this report, the rescue service is accountable to the Ministry of Justice and the Police and is managed by the two rescue coordination centres (HRS), located at Sola (HRS southern Norway) and Bodø (HRS northern Norway). In the event of accidents in the North Sea, the rescue helicopter service (330 squadron) at Sola airport is scrambled. There is a mandatory 1 hour standby. In order that a doctor can be included in the crew, one must be notified by a special procedure which varies depending on the time of day. This may lead to departure being further postponed. According to the 'Report on the rescue helicopter service' issued on 12.12.1996, it is a regional authority responsibility to provide medical crew for the rescue helicopters on standby. The AAIB/N believes that the doctor (if he is to be part of the crew) should be on watch at the base in the same way as the rest of the crew.

2.8.2.2 It is planned that the rescue helicopter should be able to reach the distressed North Sea workers at a point furthest away from Sola within 1.5 hours' direct flying. With the standby time which the rescue squadron has at the moment, the person in distress must be equipped with aids to be able to survive for at least 2.5 to 3 hours before an anticipated rescue can take place. This must be a starting point for the authorities to establish requirements for the standard and quantity of emergency equipment to be included on personnel transportation flights over the North Sea. Two and a half hours in the sea in winter appears to the AAIB/N to be a long time with the emergency equipment which is in use today. The AAIB/N believes that the authorities should consider improving the standby time for the rescue helicopters in order to shorten the time that the person in distress is exposed to cold and water. This is in accordance with the position taken in the 'Report on the rescue helicopter service' in which it is indicated that the reaction time for rescue assignments should be set at 15 minutes, 24 hours a day. This must of course apply to all rescue bases.

2.8.3 Rescue Coordination Centres (HRS) - several variations of notification and communications

2.8.3.1 In conversations with the AAIB/N shortly after the emergency landing, a manager at the HRS expressed the feeling that he regarded the standby time of one hour to be dangerously long, and that it should be evaluated by a committee (see 1.18.11.3). More precisely, it was also stated that the notification procedures for the rescue squadron functioned excellently, but that the procedures for notifying doctors might make the start of a rescue mission more complex and might possibly delay it.

The rescue coordination centres are equipped with advanced communications equipment, and are in direct contact with all important partners within the rescue service. This makes it possible to process incoming messages quickly and efficiently. In this way, the coordination and control of the rescue mission can be carried out. In this emergency landing, the persons in distress were also equipped with communications equipment, but it was not used, partly to avoid interference with the emergency location signals. There was no need for communication since the rescue mission was launched so quickly, and there was visual contact with the victims within a very short time after the emergency landing.

2.8.3.2 One feature which the AAIB/N wishes to point out is that the release and activation of the ELT can make communications difficult on some emergency frequencies. The AAIB/N is of the opinion that the authorities concerned should evaluate the degree to which it should be necessary to maintain communications with people in distress from aircraft accidents/incidents at sea and if the use of a maritime communications channel should be used in this context.

2.8.4 Briefing and evacuation

2.8.4.1 After the technical problems with the helicopter arose, the crew carried out the ditching procedure with great skill. The flotation gear mounted on the helicopter functioned as it should, and it remained afloat as intended (and long after the rescue of the passengers). One feature of successful evacuation and survival depends on the helicopter having sufficient buoyancy, stability, practical emergency exits and efficient life raft equipment. In this emergency landing, the buoyancy and stability were good. In addition, the passengers and crew must also be equipped with the best emergency equipment available.

2.8.4.2 During the descent, the Pilot-in-Command gave the passengers a short briefing about the problems which had arisen and the crew's plans for further action. A general announcement (Emergency Passenger Briefing) is printed on page 2 of the Emergency/Abnormal Checklist. The Pilot-in-Command did not follow the printed information. This is understandable because of the short time available. He concentrated on the use of the passengers' survival suits.

2.8.4.3 The use of life jackets was not covered in the briefing, but it is included in the printed safety information which is located in the seats. After the passengers understood that there was going to be an emergency landing at sea, some of them took out the life jackets and, with varying degrees of success, tried to put them on over their survival suits. Since the suits were of different designs, some with flotation chambers and others without, it is difficult to prepare a general guide to how these survival aids are to be used. The AAIB/N is of the opinion that there is a need for clarification in this area. It would clearly be advantageous if a common standard were to be applied to the suits.

2.8.4.4 The problems which arose later during the evacuation from the helicopter should be analysed by skilled rescue personnel in cooperation with the CAA/N, with the aim of possibly improving the use of the equipment. An analysis of whether this emergency equipment is best suited to operations in the North Sea should also be subject to a thorough review. In the first instance, only one life raft was accessible, and it was partially destroyed after a short time. After the second life raft was made available with great difficulty, its usefulness was limited since it was no longer affixed to the helicopter.

2.8.4.5 As this evacuation developed, most of the passengers and the Co-pilot became dependent on the capacity of the helicopter to remain afloat and the characteristics of their survival suits. The AAIB/N believes that this functioned so well because the weather conditions were favourable and the rescue service arrived on site so rapidly. A second important feature was that all of those involved had attended adequate training courses and that both the crew and the passengers retained the necessary composure.

2.8.5 Survival suit requirements for pilots and passengers

2.8.5.1 Both passengers and crew involved in helicopter traffic in the North Sea are equipped with survival suits. The requirements for survival suits are not specified by the aviation authorities, but by the various oil operators. The Norwegian Petroleum Act requires that everyone spending time on an installation in the North Sea must have access to a survival suit. The operators have also decided that these suits must be used while in transit. The oil industry has informed the AAIB/N that one of the main reasons for this is because at least 35% of those working on oil installations are unable to swim. The oil operators have had 4 different types of suit approved by the Norwegian Directorate of Shipping and Navigation. It has proven difficult to reach an adequate solution which satisfies all the requirements which this type of survival suit must meet. It is a matter of the colour of the suit, its use in combination with a life jacket, reflectors, lights (strobe lights), cuffs, gloves, swimming goggles and knife.

2.8.5.2 As regards the passengers, since they normally only wear these suits during transportation to and from the installations, the primary requirement is that a person in distress should be able to survive immersion in cold water for a certain period prior to a rescue being effected. The suits which are currently available, and which have been approved by the Norwegian directorate of Shipping and Navigation, satisfy this objective to a certain extent. The AAIB/N believes that it is unfortunate that the suits are of varying manufacture and of varying designs. Some have boots (socks), others do not; some have flotation chambers, others do not. When this emergency landing took place, it appeared that the suits' properties were not fully utilised. None of the passengers made use of the flotation chambers, and the legs of those passengers who had suits with no boots quickly became cold. Some people did not know that there were gloves in the sleeves of the suit. Since the time the passengers are wearing the suits is relatively short, the requirement for comfort is not so important. Hygienic use of the suit is also a feature which must be taken into consideration.

2.8.5.3 For the crew, who would normally be wearing survival suits for an entire working day, the problems are different. Here, the requirement for comfort in the working situation is greater, and this has been an important factor in the design of the suit. The members of the crew, however, have important tasks to carry out in every emergency situation. One precondition, therefore, must be that, as regards warmth, the suits are designed such that the crew can take care of the passengers at all times.

During this emergency landing, the crew was wearing clothing which consisted of non-insulated survival suits without hoods, plus gloves, plus a blue cotton flying suit on the outside. Under the survival suit, they were wearing light clothing. This suit could not prevent both crew members becoming seriously chilled. If they had not been rescued so quickly, during this emergency landing, the crew could have ended up in a very serious situation, leaving the passengers to their own devices, possibly having to take care of an incapacitated crew. The AAIB/N therefore finds it unsafe that the crew is not better protected against hypothermia than its members were in this situation. In addition, the AAIB/N also finds it unsafe that the crew were dressed in a dark suit when all other important equipment for use when ditching at sea, is coloured orange.

The AAIB/N is aware that the company is working together with the employees on producing designs for various suit types for the crew which should be able to combine the possibility of survival in cold water over a period of time with the necessary level of comfort. Since work is constantly being carried out on improving this equipment, and new requirements will arise regarding survival suits for crew members once JAR OPS-3 becomes valid, the AAIB/N will not put forward any advice in this context. Nevertheless, importance should be attributed to the AAIB/N's views in any future proceedings regarding the selection of suits for crew members.

2.8.5.4 One matter which is of great importance to both passengers and crew is what they are wearing under the survival suit. It is recommended (for example in JAR) that warm garments (thermal liners) are worn under the survival suit when the sea temperature is lower than +10°C. For operations over the North Sea, this would be more or less all year round. The AAIB/N believes that the company, the oil operators and the public bodies must inform everyone travelling across the North Sea about the importance of being well clothed under the survival suit. In collaboration with the petroleum industry operators, the authorities should also undertake continual reviews of whether the equipment which is currently available to passengers and crew, is best suited for its purpose. In addition, it should be noted that, in the coming JAR on helicopter flights, emphasis is to be placed on the insulation qualities of clothing worn under survival suits.

2.8.5.5 The helicopter is equipped with 4 extra survival suits, (Quick Donning Suits), of which 2 are intended for crew use. None of these suits was used.

2.8.6 Requirement regarding the use of life jackets - compatibility with wearing survival suits

2.8.6.1 In the Norwegian regulations, BSL D 2-1, it is stated that life jackets or equivalent buoyancy devices should be carried on board the aircraft. The term 'equivalent buoyancy devices' means that, for example, the seat cushion is designed (and equipped) as a flotation device. As mentioned previously in the report, during conversations with the passengers, the AAIB/N gained the impression that confusion reigned with regard to the use of life jackets. Another matter which came up in conversation was that it was very difficult to put on the jacket over the survival suit. This matter also came up during the investigation into the Super Puma accident in the UK sector. In that case, the people in distress were in the process of drowning because their partly-attached jackets moved upwards, making it difficult for them to hold their heads above water. The AAIB/N believes that there is a need to adapt these items of survival equipment to be compatible with one other. It should be noted that current survival suits are not equipped with a light, so according to current arrangements, the passengers must wear a life jacket to adhere to the aviation regulations which state that the jacket must be equipped with a light.

2.8.6.2 The AAIB/N believes that the CAA/N, working with the helicopter companies and the oil industry, must look more closely at the mandatory use of survival suits for passengers (made mandatory by the oil operators) and whether life jackets do need to be used at the same time during an emergency landing at sea, and how such a combination can be used in practice.

2.8.6.3 One result of the round of hearings for this report is that the AAIB/N was made aware, by the CAA/N, of the fact that countries which operate heavyweight helicopters over sea, have been assessing the problem areas related to the use of rescue equipment for passengers, through the JAA. This has led to the wording of the future JAR-OPS 3, par. 3.825 being more specific than the text in ICAO Appendix 6. The joint European regulations (JAR), coming out shortly, state that helicopters which fly over water must be equipped with a life jacket with a light for each person. No alternative 'equivalent buoyancy equipment' will be permitted, such as seat cushions.

In the JAA Helicopter Subcommittee, there have been discussions on several occasions about the amount of detail which should be used in regulating each individual passenger transport and therefore the equipment with which the individual passenger should be provided. To date, the conclusion is that no requirement has been specified regarding 'Survival Suits' applying to passengers. One of the working parties appointed by this committee, the Helicopter Offshore Safety Survivability Working Group, has this as a speciality area. This group combines the expertise gained from long experience of helicopter flights on the Continental Shelf.

One of the problems pointed out by this report regarding the passengers' clothing is that the oil operating companies make it mandatory for passengers to wear suits, while the regulations specify the use of life jackets. A combination of the two has proven to be dangerous. In AAIB/N's opinion, it is disturbing that JAR-OPS 3, in its current wording, does not take into account the problem which has been raised by both the UK authorities and now the AAIB/N, namely the way in which the passengers' survival suits, used in conjunction with a life jacket, could possibly be coordinated safely. In AAIB/N's opinion, the combination should be tested under conditions which are as realistic as possible.

2.8.7 Emergency locator transmitters (ELT) - requirements on type and usage

2.8.7.1 Locating an aircraft which has made an emergency landing can be very time-consuming. In BSL D 2-2, the CAA/N has therefore included requirements that all Norwegian-registered helicopters must be equipped with an automatic emergency radio (locator transmitter), for which the correct English term is Emergency Locator Transmitter (ELT). The AAIB/N assumes here that the use of the expression 'VHF emergency radio' in the BSL mentioned above is wrong and must mean emergency locator transmitter. The functions required from the ELT are:

- In the event of an accident, it must automatically begin to transmit on the emergency frequencies 121.5 and 243 MHz
- It must be possible to switch it on from the cockpit
- It must be independent of the aircraft's power supply
- It must be watertight
- It must be robust and not normally be put out of commission by an accident.

2.8.7.2 In Norway, 3 different types of emergency locator transmitter have been approved (cf. Appendix 3 to BSL D 2-1) namely: automatic permanently mounted, automatic releasable and automatic portable.

LN-OBP was equipped with 4 ELTs, one releasable, one portable and two, which can also be used for communications, in the crew's life jackets. The releasable one was activated and released from the cockpit. It was transmitting and gradually drifted far away from the helicopter. Only after two and a half days was it found and deactivated. The portable ELT was taken on board the port raft, but was never activated owing to the problems which arose there.

2.8.7.3 The JAR OPS-3, to be issued shortly, states that all helicopters operating over water must be equipped with at least one ELT per life raft. It is recommended that these ELTs must be able to operate on the frequencies of either 406 MHz and 121.5 MHz or on 121.5 MHz only. It must be noted that it is no longer a requirement to use the frequency 243 MHz, either in ICAO Annex 10 or the coming JARs. In the opinion of the AAIB/N, the CAA/N's requirements for ELTs are outdated (dating from 1981) and should have reflected the requirements contained in ICAO Annex 10.

2.8.7.4 During this emergency landing, no attempt was made to communicate on any emergency frequency so that there would be no jamming of the signals from the released ELT. The AAIB/N believes that the authorities should evaluate the use of the various frequencies to prevent the possibility of essential communications being jammed in future.

2.8.7.5 There is reason to question whether releasing the ELT was, in this case, the correct action. The emergency checklist says "Activate" (not "Deploy"). In the AAIB/N's opinion, this clearly means that the fuselage-mounted ELT must be activated to issue a signal and nothing else. In the board's opinion, it was unfortunate in this case that it was released from the helicopter. This meant that the ELT quickly drifted away from the helicopter and as time went by became of little value to the rescue mission. At the same time, it was transmitting continuously and if the weather had been poor it would have been almost impossible to stop it. It would therefore create difficulties for another, and perhaps more serious, emergency situation, in which a search would be dependent on emergency locator transmissions from other people in distress. The CAA/N should look both at the appropriateness of the types of ELT being used on helicopters which are involved in oil-related activities, and the way in which they are to be used.

2.8.8 Communications - use of 121.5 MHz - possible use of maritime channel 16

2.8.8.1 In a note made by the Rescue Coordination Centre for southern Norway (HRSS) after the rescue mission for the emergency landing on 18 January 1996, concerning the options for communicating with the people in distress, it is stated:

> "There was no possibility of radio communications between the participating rescue units and the people in distress. There is no requirement for a communications radio (121.5 and/or 123.1, or channel 16) in life rafts or on aircraft."

2.8.8.2 During the emergency landing, both pilots had their own emergency radio which could operate on the 121.5 MHz frequency, both as an emergency locator transmitter and as a radio. These radios were not used since no requirement for communication arose. It must be noted that there is no requirement for emergency radio communications in aviation.

The AAIB/N believes that an evaluation should be made of whether, with regard to potential jamming because of the ELT transmission, it should be possible for the people in distress to transmit on a maritime channel, which is highly accessible in the maritime environment and also, of course, to the rescue helicopters. The AAIB/N knows that some emergency radios on the market offer this option. The AAIB/N believes that the authorities concerned should evaluate the problems surrounding radio communication with people in distress after helicopter accidents/incidents at sea.

2.8.9 Evaluation of 'Hostile Sea'

'Hostile Sea' is a designation used to refer to the waters north (south) of 45°N (S). This is given in the coming JAR-OPS 3, for example. In other words, the North Sea is included in this category. In order to provide people in distress in this region with the best chance of rescue, a series of conditions must be satisfied:

- The helicopter must be equipped for operations over such waters
- The passengers and crew must be well trained and equipped
- A rescue service must have properly adapted equipment

- The rescue service should provide a standby service which is designed so that people in distress at the furthest limits of the area can be rescued within 3 hours
- The authorities concerned must regulate the operations
- Weather conditions must be acceptable
- The wave height must be no greater than will allow a successful ditching to take place.

In addition, it should be mentioned that individual operators within the offshore industry have decided not to permit helicopter operations when weather conditions and wave heights exceed set values.

2.8.10 Safety training for pilots and passengers

2.8.10.1 Safety training for the transportation phase is carried out at various institutions. Pilots are trained primarily at NUTEC in Bergen. The training which is provided for passengers covers safety and emergency training, both for helicopter flights and for their stay on the installation.

The AAIB/N has gained the general impression that the training is thorough, and that the participants are satisfied with the quantity of training and the periodic refresher courses (altso see comments in 2.8.11.5). The AAIB/N believes that a greater degree of shared training between pilots and passengers would be ideal and would increase safety. At the same time, this would also provide the people concerned with a greater understanding of the different problems/responsibilities of the various personnel groups during an emergency situation.

2.8.10.2 The AAIB/N believes that the great amount of experience gained by helicopter companies and operators over the last 30 years of petroleum operations in the North Sea have given must be exploited to the full. Continual investigations are carried out into various facets of this industry/transportation. It is important that there is an exchange of international experience, and that this information is available to the people concerned. The AAIB/N believes that updating based on experience from rescue operations must be utilised to the full in safety training.

2.8.11 Helicopter rescue equipment

2.8.11.1 The helicopter was equipped with rescue equipment in accordance with regulations. How the equipment was used and how it functioned is dealt with in detail in section 1.15.2.

As mentioned previously, the AAIB/N wants to direct attention to the requirement for clarification on the use of life jackets when the passengers are equipped with survival suits at the outset. In addition, the AAIB/N questions the operation of the rafts, which was not particularly successful for either the port or starboard raft. The AAIB/N regards the fact that this did not cause greater problems during the rescue operation as being due to the good weather conditions. The company ought to evaluate whether the rafts' mounting point, attachment arrangements (lines, etc.) and the equipment are the best available. The marking of lines/ropes should be reassessed (e.g. that the entire line attaching the raft to the helicopter should be red). An evaluation should be made of the procedure for arming and releasing both rafts from the cockpit at the same time. In addition, all equipment on board the raft should be in accordance with the information given during training.

2.8.11.2 The sea anchor did not function as intended. This might be explained by the fact that the helicopter, in accordance with company procedure, was put down onto the water with the wind coming at approx. 30° from starboard, therefore drifting over the sea anchor. In its internal report after the accident, the company has pointed out precisely this situation and wishes to evaluate whether the procedure should be changed to put the helicopter down on the water with the wind coming from the opposite side. The AAIB/N agrees that such an evaluation is necessary.

2.8.11.3 The need for a knife arose on several occasions. The company, together with the operators, should evaluate whether survival suits should be equipped with a knife.

2.8.11.4 The need was expressed for something for the passengers to hold on to, on both sides of the helicopter, after having boarded the raft.

2.8.11.5 On the basis of the training which the Pilot-in-Command had carried out at NUTEC just before the emergency landing, he gained the impression that there should be one or more paddles in the raft. HS had removed this (these) several years previously. This raises the question of how the company coordinates emergency training for the crews, with the company's own specifications and standards when such training is carried out externally. The company should, in future, ensure that emergency training is realistic in relation to the way in which the company's helicopters are equipped.

2.8.11.6 The tie-down hooks which are mounted on the sides of the helicopter's fuselage should be fitted with covers since these created great problems, in that the ropes from the raft became trapped on the hook on the windward side of the helicopter.

2.8.12 'Top-cover' helicopter

2.8.12.1 A helicopter from Norsk Helikopter AS arrived shortly after the ditching had taken place. The helicopter remained in the vicinity of the ditched aircraft until the rescue helicopters arrived on site. This helicopter was viewed as psychological support by the passengers and was therefore a positive element. The Rescue Coordination Centre (HRS) has also expressed the same conviction in connection with an evaluation which was undertaken after the rescue mission.

2.8.12.2 One situation, however, which will have to be looked at in more detail by HRS in this context, is that some of the passengers found the noise from this helicopter disturbing, not least in connection with verbal communications which were necessary between the people on the ditched aircraft.

2.9 The company's internal investigations

The AAIB/N believes that, in the name of aircraft safety, it is very positive that the company has established procedures for the internal processing of incidents and accidents. An important feature of carrying out this type of work is to have the requisite objectivity. In this case, through its investigation team, HS has carried out a good, objective piece of work and has drawn up a series of recommendations and measures which contain both short-term and long-term safety aspects. Nevertheless, the AAIB/N has noted that, in its report, the company touches on the maintenance programme for the helicopters in question in this report, but does not put forward an opinion on the general and principal maintenance-related conditions which are described in the company's manuals and which may have an influence on the programme. In particular, this applies to the master documentation. As a reason for this, the company's management states that the internal investigation team reached the opinion that there were no circumstances worthy of criticism in the maintenance programme or its management. The AAIB/N believes that it might be appropriate to aircraft safety for the investigation team's assessment to be put forward clearly in the internal report together with the reasons which may have formed the basis for the team's coclusions within the area.

3 CONCLUSIONS

3.1 Findings

3.1.1 <u>General</u>

a) The helicopter had valid registration, environmental and airworthiness certificates.

b) The helicopter's mass and the location of its centre of gravity were within permitted limits.

c) The crew were in possession of the necessary licences and had undergone the required training.

d) The crew's working hours and rest time prior to the emergency landing were within the limits laid down in the regulations.

e) The crew members were not suffering from any medical conditions which would have been of any significance to this emergency landing.

f) Weather conditions during the emergency landing: Wind 150° 25 kt., cloud base approx. 600-700 ft, visibility approx. 6 km in drizzle, no icing, air temperature 4° - 5°C, sea temperature 5° - 6°C and wave height 3-4 m.

g) The helicopter was equipped with emergency equipment for flying offshore as required by the aviation authority (CAA/N).

h) The helicopter was equipped with an acoustic transmitter (a pinger) which was transmitting incorrectly on too high a frequency due to an internal failure.

i) The helicopter was equipped with a CVFDR. The information from the magnetic tape was, to a great extent, undamaged despite the time it spent at the bottom of the North Sea.

3.1.2 Technical matters

a) The helicopter was maintained on the basis of a maintenance system approved by the CAA/N.

b) LN-OBP was not equipped with full de-icing equipment. As a result, the main rotor blade's de-icer elements were not connected.

c) The leading edge strip on main rotor blade S/N 617 had a total of 1,590 hours of operation at the time of the emergency landing.

d) The vibrations which the crew felt prior to the emergency landing were caused by a fold of the leading edge strip of main rotor blade S/N 617 which became raised from the base layer and folded out into the air flow.

e) The erosion along the leading edge strip was caused mainly by water droplets (liquid impingement erosion).

f) A great part of the pattern of cracks on the leading edge strip was created as a consequence of dynamic loading (fatigue cracks).

g) There was no formal contact between Eurocopter and HS in which the problem of a high rate of erosion on titanium leading edge strips was taken up for debate. In relation to the factory, HS has neither submitted reports not complained about the relatively high rate of replacement.

h) The AAIB/N has not found the main rotor blade to be subject to 'abnormal' loading which led to the relevant pattern of damage existing prior to the emergency landing.

i) The company's Maintenance Requirement List states that the main rotor blade is maintained in accordance with Hard Time (HT) and On Condition (OC).

j) According to information provided by HS, the rotor blade in question had been inspected in accordance with MET 62.10.00.603 three times during the course of the last 260 hours, the latest being 38 hours prior to the emergency landing. These inspections were completed without any remarks.

k) Tests carried out on the main rotor blade in question have shown that the prescribed 'tapping' method did not uncover all forms of deficient bonding between the leading edge strip and the underlying materials.

l) The technicians who carried out the last DMC and PFC, respectively, prior to the departure on the day in question, did not raise any issues regarding the main rotor blade.

m) On the basis of the examination of the blade, the AAIB/N finds that there is reason to believe that the leading edge strip was not really airworthy when the last DMC and PFC were carried out. This assessment is based on the airworthiness criteria in MET 62 10.00.603.

n) The maintenance programme for main rotor blades with titanium leading edge strips meant that the blades was, in priciples, subject to a detailed inspection every 500 hours of operation. Based on knowledge of this type of blade, the AAIB/N believes that this kind of inspection frequency is not consistent with the principles on which "On Condition" maintenance is based.

o) The AAIB/N finds that there is no reason to criticise the work which, based on the company's maintenance data, was carried out by company technicians on main rotor blade S/N 617 during the last DMC and PFC.

p) There have been proven fatigue fractures in secondary cracks (transverse cracks) in the outer 28.5 cm of the leading edge strip. In all probability, these cracks were present before the helicopter's last departure. In addition, it is probable that the cracks could not be detected using the prescribed maintenance procedure.

q) The leading edge strip of the main rotor blade was modified in accordance with 'Eurocopter Technical Instruction No. 230'. Drawing up this modification implied no structural calculations from the factory. The reason for this was that the designer had decided that the remaining bond between the titanium strip and the de-icer element was homogeneous and sufficient, and that it was therefore not necessary to make new calculations.

r) The technicians in the company were not informed of the modification of the leading edge strip, carried out by Eurocopter. As the reason for this, the company's management states that the modification did not have any maintenance-related consequence and did not require any other attention from the maintenance organisation.

s) A series of statements in the HS system of technical manuals makes it necessary, in the opinion of the AAIB/N for the company to examine the manuals system critically both regarding text and coordination.

t) At the time of the accident, the type of blade in question had logged approx. 400,000 blade operating hours globally. HS had logged 100,000 blade operating hours.

u) As far as the AAIB/N can ascertain, the accident in question was caused by the only known case of parts of the titanium leading edge strip becoming loose on main rotor blades on Eurocopter AS 332 helicopters.

3.1.3 Personal safety

a) All passengers were wearing insulated survival suits (made mandatory by the employer) approved by the Norwegian Directorate of Shipping and Navigation, but of varying types.

b) The crew were wearing blue non-insulated survival suits which could not prevent them becoming wet, and both began to suffer from hypothermia.

c) All passengers had attended adequate emergency training. This type of emergency training is carried out at various institutions.

d) The emergency training cources which the pilots attended at NUTEC contained discrepancies in relation to company standards.

e) When it was decided that an emergency landing should be carried out, the Pilot-in-Command transmitted a MAYDAY which was received by the Air Traffic Control Centre (ATCC) at Stavanger.

f) The life rafts were released from the cockpit electrically. The starboard raft (on the windward side) blew up onto the roof of the helicopter and remained lodged beneath the rotor.

g) It was necessary to cut all lines to free the starboard raft. Because of this, the people on board were unable to keep the raft beside the helicopter, and it drifted away with only four persons on board.

h) One of the The tie-down hooks which are mounted on the side of the helicopter's fuselage created problems for releasing the raft, because the raft's lines/ropes became caught on the hook.

i) The need to use a knife arose on several occasions. The passengers' suits are not equipped with knives.

j) The upper tube on the port raft was punctured by part of the tail boom structure.

k) The helicopter's sea anchor was released, but was of no use.

l) The fuselage-mounted emergency locator transmitter was due to incorrect use of procedure released from the helicopter and was automatically activated at the same time. It drifted away from the helicopter and was located at Karmøy after two and a half days and deactivated.

m) The portable emergency locator transmitter was taken on board the port raft, but was never activated.

n) There was nothing for the people in distress to hold onto (grab lines) along the helicopter's floats after they had boarded the rafts.

o) The Co-pilot and 13 passengers were rescued from the floating helicopter by the first rescue helicopter approx. 1 hour after the emergency landing.

p) The Pilot-in-Command and 3 passengers were rescued almost simultaneously from the starboard raft by the second rescue helicopter.

q) The equipment in the survival suits was not fully utilised.

r) It appears to be difficult to put on a life jacket over a survival suit.

s) The members of the crew did not find it expedient to use their emergency radios.

t) The rescue helicopter service has a mandatory standby time of one hour all year round.

u) It is planned that, from its base, a rescue helicopter should be able to reach persons in distress at sea off the Norwegian coast, and at a point furthest away from the base, within 1.5 hours of direct flying time.

v) It must be regarded as fortunate that a fully operational rescue crew was available at the time of the emergency landing allowing the rescue helicopter to take off just 11 minutes after the alarm was raised. That a further helicopter was available with a complete crew shortly after the first one must also be regarded as fortunate.

w) A helicopter from the company Norsk Helikopter AS arrived on-scene a short time after the emergency landing and circled near the stricken helicopter. The passengers found this to be comforting, on one hand, but also disturbing to communications between the persons on the ditched aircraft, because of the noise.

3.2 Significant findings

The AAIB/N has evaluated the following results of the investigation as being of particular importance from the viewpoint of flight safety, seeing as these factors either had direct consequences or might have indirectly had a bearing on the chain of events:

a) At the time of the emergency landing, the outer part of the leading edge strip was weakened by erosion/perforation.

b) The investigation has shown that, before the emergency landing, the leading edge strip had contained areas which had deficient or weakened bonding with the base layer.

c) A modification of the leading edge strip, which was carried out by Eurocopter, weakened the strip at the blade tip.

d) Erosion/perforation, deficient or weakened bonding and the modification each individually represented no threat to aircraft safety. These factors in combination, however, weakened the leading edge strip sufficiently to cause a fold on the strip to lift up from the base layer and to project into the flow of air. This was due to the aerodynamic forces exceeding the limits for the mechanical load which the strip could withstand at the time in question.

e) In the opinion of the AAIB/N, there is potential for improvement in the design and maintenance requirements of the manufacturer, Eurocopter, as regards the main rotor blade's leading edge strip of unalloyed titanium. The maintenance-related assessments should be based on logical methods and relative to the use of such blades under varying operational conditions.

f) It must be stated that the company's maintenance program for subject helikopter type, which was based on that of the manufacturer, did not have any in-built characteristics for identifying fault development, which is just what happened in this case. The AAIB/N believes that better utilisation of the procedures and principles, which are laid out in the company's management documentation, might have improved the maintenance program.

4 SAFETY RECOMMENDATIONS

4.1 All recommendations forwarded to the CAA/N

It is recommended that:

4.1.1 The factory (Eurocopter) examines its basic design data for main rotor blades using Titanium T-40 leading edge strips in relation to liquid impingement erosion.

4.1.2 The factory and Helikopter Service AS change the maintenance programme for main rotor blades with titanium leading edge strips made of Titanium T-40, to prevent, if possible, the recurrence of any situation similar to that dealt with by this report.

4.1.3 Helikopter Service AS undertakes a critical review of its technical manuals system, particularly with regard to management documents, both with the purpose of assessing its textual content and coordination.

4.1.4 The CAA/N assesses the coordination of the use of the aircraft's life jackets while using the passenger survival suit for people being transported by helicopter to and from offshore oil installations.

4.1.5 The CAA/N assesses whether to introduce any requirements for emergency radio for use in rafts on helicopters which are flying to offshore oil installations, and whether these should be able to communicate on the maritime communications channel.

4.1.6 The CAA/N and Statens Teleforvaltning [the Norwegian National Telephones Administration] assess relevant regulations as regards type, name and use of emergency locator transmitters (ELTs), and which are of greatest value to helicopters flying to offshore oil installations.

4.1.7 The CAA/N assesses type and use of rescue equipment in helicopters flying to offshore oil installations.

4.1.8 Helikopter Service AS should consider finding solution(s) for preventing lines/ropes from rafts becoming caught on the tie-down hooks which are located on the sides of the helicopter.

4.1.9 The CAA/N should ensure that there is a control system at the operator's premises to ensure that acoustic transmitters (pingers) are transmitting at the prescribed frequency.

4.1.10 The Ministry of Justice and the Police should consider requirements for standby times for rescue helicopter crews which are shorter than current requirements, cf. the recommendation in the 'Report on the rescue helicopter service', dated 12 December 1996.

5 APPENDICES

1. The scene of the accident

2. Extract from the Eurocopter Maintenance Manual (MET), 62.10.00.603.

3. Relevant abbreviations

AIRCRAFT ACCIDENT INVESTIGATION BOARD, NORWAY (AAIB/N)

Fornebu, 31 MARCH 1998

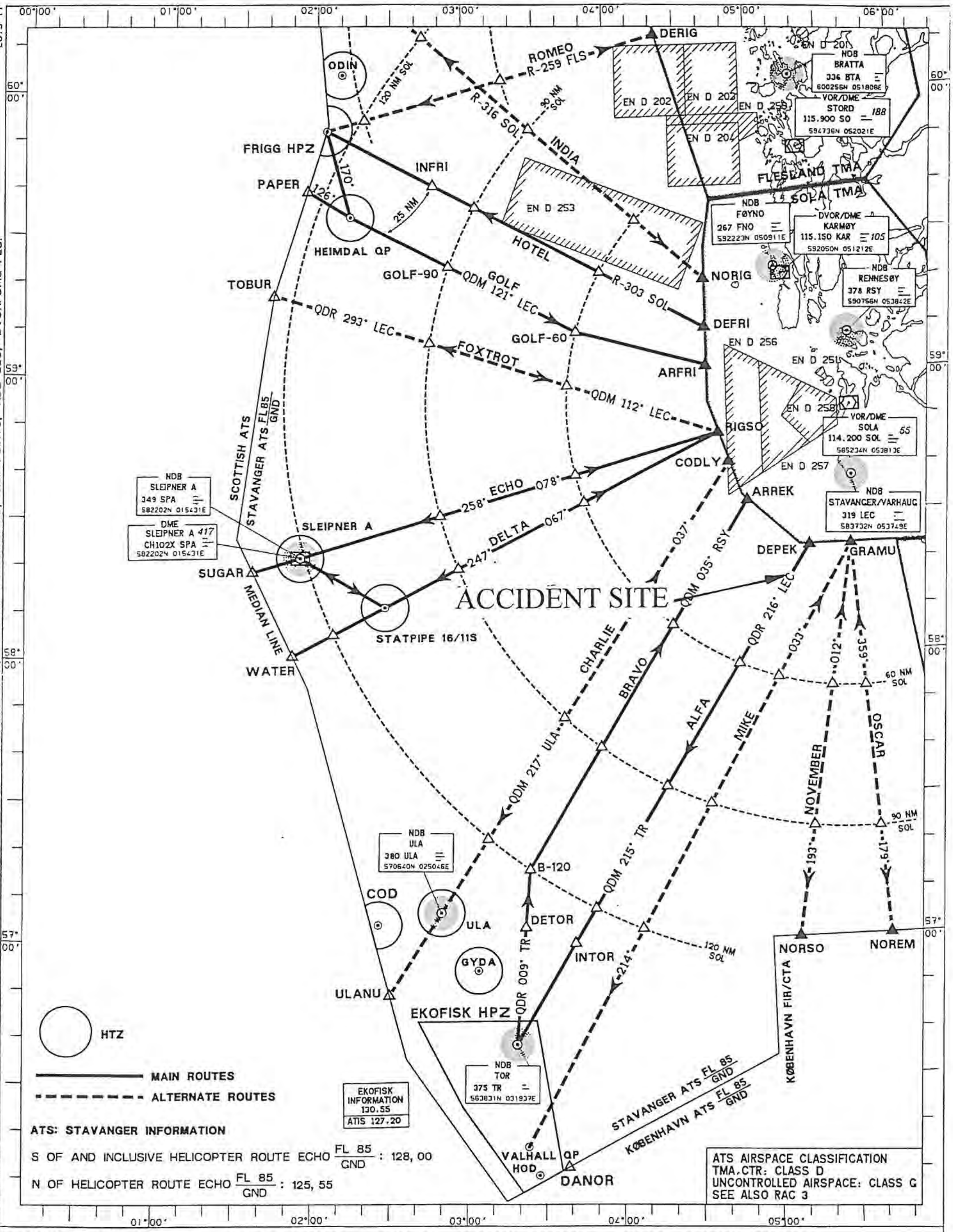
APPENDIX 1

HELICOPTER ROUTES - NORTHERN NORTH SEA - PART

SCALE: 1:2 000 000

LGIS 11

CHANGES: HAR C REVISED, HAR N AND HAR O NEW, STONE RENAMED TOBUR, CODNO DELETED, ULANU NEW, REVISED COORDINATES, REP POINTS, NDB LEC, DVOR/DME FLS.



ATS: STAVANGER INFORMATION

S OF AND INCLUSIVE HELICOPTER ROUTE ECHO $\frac{\text{FL 85}}{\text{GND}}$: 128, 00

N OF HELICOPTER ROUTE ECHO $\frac{\text{FL 85}}{\text{GND}}$: 125, 55

ATS AIRSPACE CLASSIFICATION
TMA,CTR: CLASS D
UNCONTROLLED AIRSPACE: CLASS G
SEE ALSO RAC 3

REPORTING POINTS:

ARFRI	590140N	044000E	**FRIGG QP**	595242N	020354E	**NORSO**	570000N	051030E
ARREK	583253N	045521E	**GOLF 60**	590931N	034654E	**PAPER**	593948N	015606E
B-120	571537N	032537E	**GOLF 90**	592346N	025424E	**RIGSO**	584727N	044415E
CODLY	584122N	044815E	**GRAMU**	582303N	053631E	**SUGAR**	581854N	013525E
DANOR	561211N	033853E	**HEIMDAL QP**	593426N	021344E	**TOBUR**	591738N	014249E
DEFRI	590950N	044000E	**INFRI**	594109N	024744E	**TOR**	563831N	031937E
DEPEK	582214N	051901E	**INTOR**	565952N	034307E	**ULANU**	564908N	023021E
DERIG	601211N	042144E	**NOREM**	570000N	054612E	**WATER**	580109N	015142E
DETOR	570322N	032336E	**NORIG**	592018N	044000E			

LUFTFARTSVERKET, NORGE

07 NOV 1996

BONDING CHECKS BY TAPPING:

- Sound check the blade over total bonded area
- Separations which may not be immediately apparent can be detected by lightly tapping the skin with an 80 mm x 8 mm dia. cylindrical metal object (STEEL) rounded at both ends.
- Unbonded areas give a "hollow" sound different from those produced by well bonded areas.
- Different sounds may also be obtained in a same area, owing to the various filler materials used (honeycomb, foam, roving, metal mass, etc.). (Fig.1 Detail A). R
- Sound checks by tapping also produce a different sound over repaired areas. Refer to log-card.

8. DE-ICING ELEMENT

LOCATION	DEFECT	CRITERIA	Rks	CARD No.
TITANIUM LEADING EDGE Fig.4 DET.B (item 1)	SCORE OR IMPACT WITH SHARP EDGE	No defect is permissible		/
		If defect with Max. depth 0.3 mm	5	20.60.00.422
		If defect greater.	10	
	PERFORATION	No defect is permissible		/
		If defect	1	
AREA A1 Fig.9 DET.A	SEPARATION	Chordwise width less than 10 mm over entire length of L.E.	6	
		(max. surface : 100,000 mm2 for all areas A, B, C).		

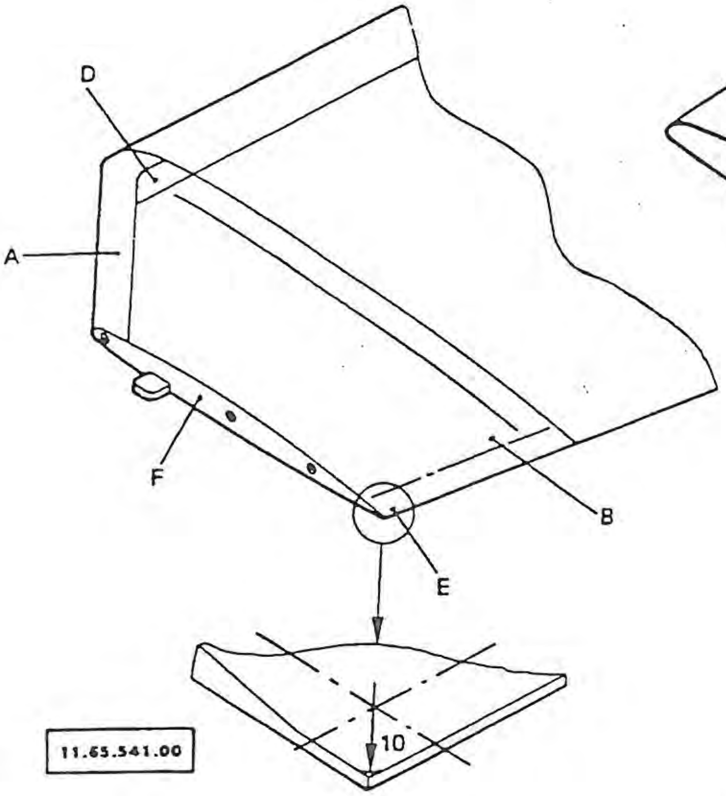
8 DE-ICING ELEMENT (Cont'd)

LOCATION	DEFECT	CRITERIA	Rks	CARD No.
AREA A1 Fig.4 DET.C	DENT WITH NO PERFORATION	12 defects acceptable per leading edge provided that they are within the limits below: - They should not cause vibration - No damage caused to the de-icing system - Located in area A1 and more than 50 mm from the ends of the leading edge - Located in a circle of dia. 8 mm - Depth less than 0.5 mm - Distance between 2 dents 250 mm	6	
		If defect greater same criteria as in previous paragraph with following modifications : - 8 defects acceptable, 20 mm spanwise and 5 mm chordwise. - Depth between 0.5 mm and 1 mm.	5	20.60.00.404
		If defect greater	10	
BLADE REDUNDANCY 332A.11.0030 .09 et .10 POST MOD OP.40626 Fig. 9 DET.B	EROSION	No defect is permissible.	11	
		If defect.	5	62.10.00.791
		If defect with glass cloth visible.	10	
	SEPARATION	No defect is permissible.		
		If defect.	10	
DE-ICER	ELECTRICAL DISCONTINUITY	No defect.	14	62.10.00.606

8 DE-ICING ELEMENT (Cont'd)

LOCATION	DEFECT	CRITERIA	Rks	CARD N°
AREA B Fig.9 DET.A) (except hatched area in Fig. 11 DET. C)	SEPARATION	On individual surface less than 5500 mm2 Total surface area less than 22000 mm2	6	
		If separation coming to an edge max. width 10 mm (Max. surface area 100,000 mm2 for all areas A, B, C).	5	62.10.00.763.
AREA C Fig.9 DET A (except hatched area in Fig. 11 DET. B)	SEPARATION	Internal bond separation, 10 mm max. chordwise dimension over the complete length of the L.E.	6	
		If separation reaches the edge: 3 areas max., with 20 mm chordwise and 12 mm spanwise dimension (Max. surface area : 100,000 mm2 for all areas A, B, C).	3	62.10.00.763
AREA D Fig.9 DET.A (except hatched area in Fig. 11 DET. B)	SEPARATION	DO NOT CHECK		
Fig.11 DETAILS B and C (hatched area)	SEPARATION	Item a : If 15 mm chordwise defect.	5	62.10.00.763
		If defect greater.	10	
		Item b : If defect less than or equal to 10 mm chordwise and 300 mm spanwise.	5	62.10.00.763
		If defect greater.	10	

A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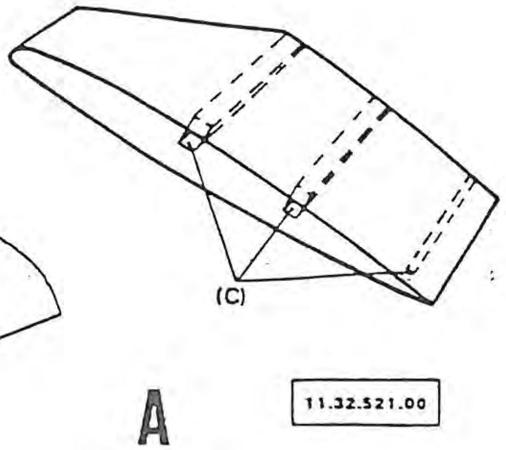
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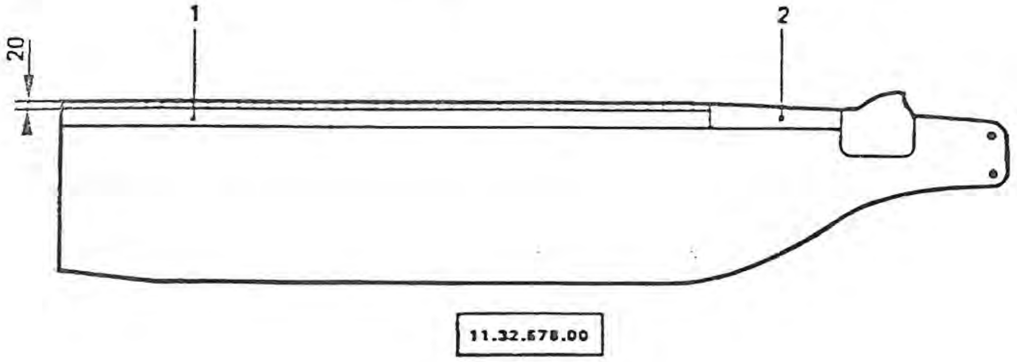
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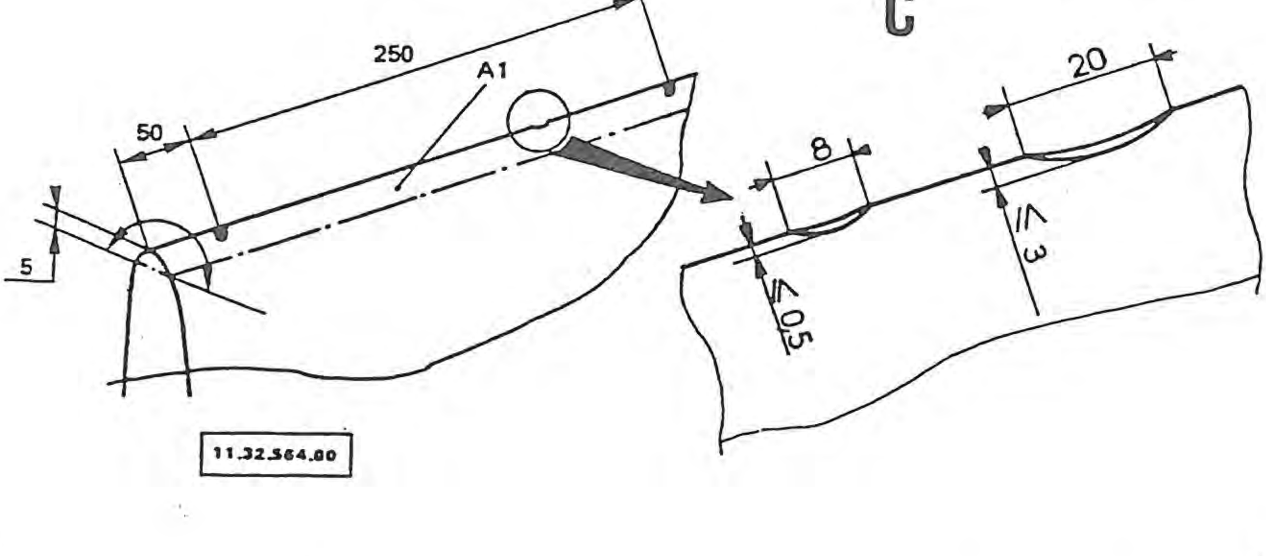
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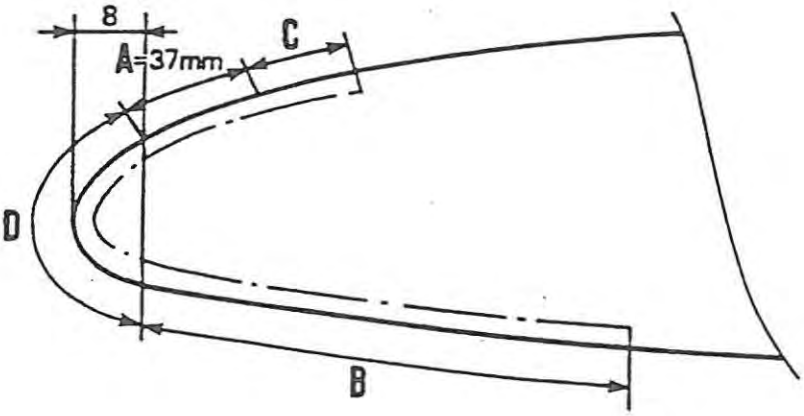
A



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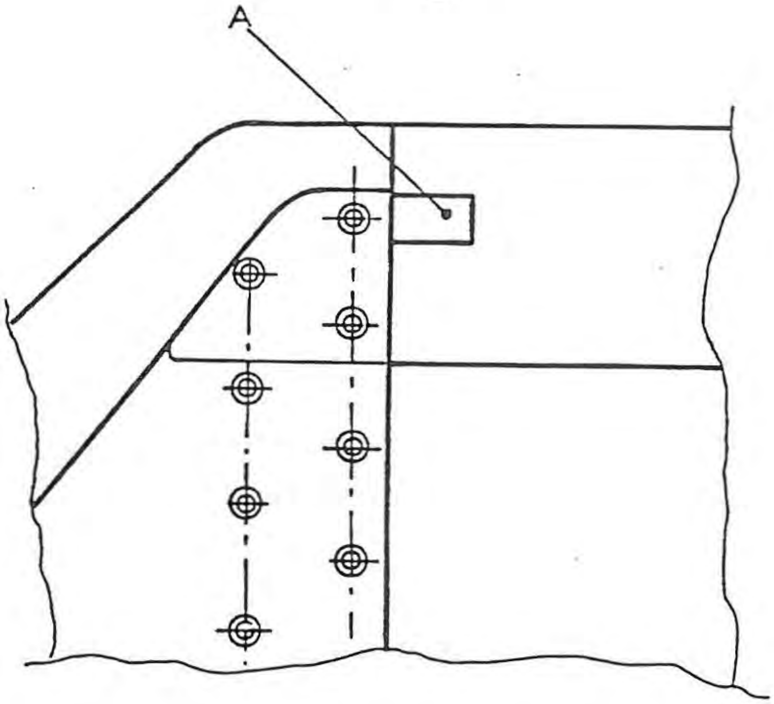

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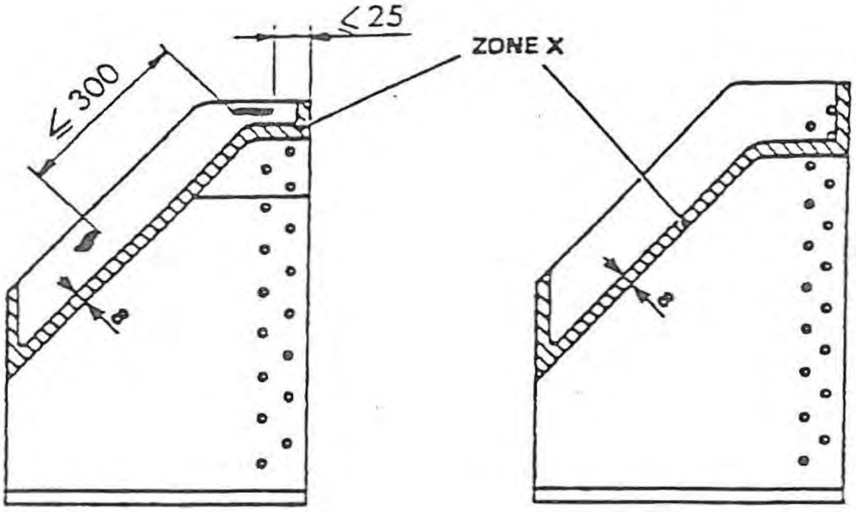

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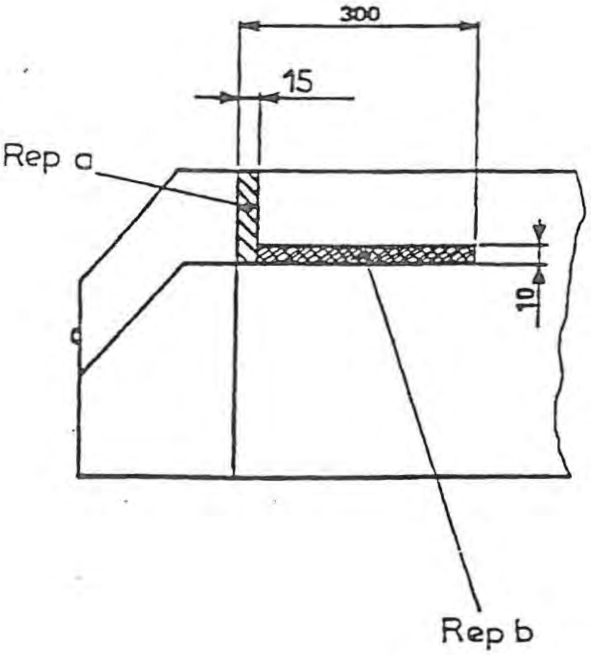

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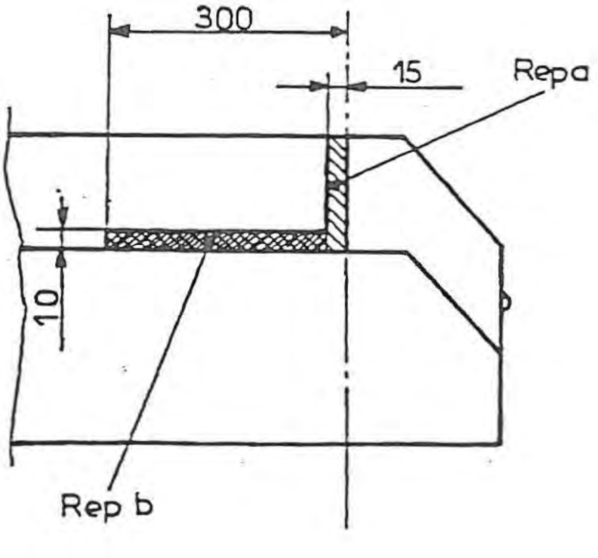

APPENDIX 3

RELEVANT ABBREVIATIONS

AAIB/N	Aircraft Accident Investigation Board/Norway (Havarikommisjonen for sivil luftfart)
A.L.F.	Check After the Last Flight of the Day
BEA	Bureau Enquêtes-Accidents (The French Accident Investigation Bureau)
B.F.F.	Check Before the First Flight of the Day
BSL	Bestemmelser for Sivil Luftfart (The Norwegian Civil Aviation Regulations)
CAA/N	Civil Aviation Administration, Norway (Luftfartsverket)
DNV	Det Norske Veritas
CQM	Company Quality Manual (HS)
CVFDR	Combined Voice and Flight Data Recorder
DMC	Daily Maintenance Check
ELBA	Emergency Locator Beacon - Aircraft
ELT	Emergency Locator Transmitter
GVI	General Visual Inspection
HFK	Håndbok for Kvalitet (Quality Manual, see CQM)
HRS	Hovedredningssentralen (Rescue Coordination Centre)
HRSS	Hovedredningssentralen for Sør-Norge (Rescue Coordination Centre for Southern Norway)
HS	Helikopter Service AS
JAR	Joint Aviation Requirements (European Regulations)

NOPEF	Norsk Olje- og Petrokjemisk Fagforbund (The Norwegian Oil and Petrochemical Federation)
MET	Eurocopter Maintenance Manual
MOM	Maintenance Operations Manual (HS)
MRM	Maintenance Requirement Manual (HS)
MSG2/3	Maintenance Steering Group document (logical methods for determining maintenance activity)
OFS	Oljearbeidernes Fellessammenslutning (Oil Workers' Union)
OLF	Oljeindustriens Landsforening (Oil Industry National Association)
PFC	Pre Flight Check
PMTD	Procedure Manual Technical Data (HS)
P/N	Part Number
PRE	French Designation for Master Servicing Recommendation
S/N	Serial Number
T.A.	Turn-around Check