# Report 98-005

# Aerospatiale AS350D

# ZK-HKU

# in-flight engine failure

# Rotorua

# 19 April 1998

## Abstract

At about 1123 hours on Sunday 19 April 1998 ZK-HKU, an Aerospatiale AS350D helicopter fitted with an AlliedSignal LTS101 engine, experienced a total loss of engine power while on approach to land at the Skyline Skyrides heliport at Rotorua. The pilot made an autorotational landing onto uneven terrain. No injuries to the helicopter occupants resulted.

The engine involved is in common use in air transport aircraft in New Zealand and overseas. Examination of the engine revealed that excessively worn gas producer turbine rotor shroud sealing rings precipitated internal mechanical failure of the engine, which resulted in a total power loss. The worn sealing rings went undetected as the manufacturer's required engine performance trend monitoring procedures were not being followed.

Safety recommendations were made relating to loose engine B nuts, the provision for securing the B nuts, correct engine performance trend checking procedures, the appropriateness of allowing a person to act as an operator's maintenance controller when also employed by the maintenance service provider, the need for all applicable requirements for engine maintenance to be carried out, and the periodic inspection requirements for the gas producer shroud sealing rings.


**Aerospatiale AS350D**

**ZK-HKU**

# Transport Accident Investigation Commission

## Aviation Accident Report 98-005

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|---|---|
| **Aircraft type, serial number and registration:** | Aerospatiale AS350D, 1132, ZK-HKU |
| **Number and type of engines:** | One AlliedSignal LTS101-600A3 |
| **Year of manufacture:** | 1979 |
| **Date and time:** | 19 April 1998, 1123hours[1] |
| **Location:** | 12 km west of Rotorua Aerodrome<br>Latitude: 38° 7 ' S<br>Longitude: 176° 11 ' E |
| **Type of flight:** | Air transport, scenic |
| **Persons on board:** | Crew: 1<br>Passengers: 4 |
| **Injuries:** | Nil |
| **Nature of damage:** | Substantial |
| **Pilot-in-Command's licence:** | Commercial Pilot Licence (Helicopter) |
| **Pilot-in-Command's age:** | 26 |
| **Pilot-in-Command's total flying experience:** | 2606 hours<br>Approximately 250 hours on type |
| **Investigator-in-Charge:** | K A Mathews |

[1] Times in this report are NZST (UTC plus 12 hours)

# 1. Factual Information

### History

1.1 On Sunday 19 April 1998 at about 1117 hours, ZK-HKU, an Aerospatiale AS350D helicopter operated by Marine Helicopters Limited (the operator), departed from the Skyline Skyrides heliport at Rotorua for a Flight Fantastic scenic flight around Mount Ngongotaha. On board were four passengers and the pilot.

1.2 ZK-HKU was based at the Rotorua Agrodome. Following a detailed pre-flight inspection of the helicopter that morning by the pilot, he positioned the helicopter at the Skyline Skyrides heliport which had an elevation of around 1500 feet above mean sea level (amsl). The pilot reported the weather as being high overcast conditions with a light wind.

1.3 As a check on engine performance the pilot selected 100% engine torque during the take-off from the Agrodome. The measured gas temperature (MGT) reading for the engine on the T4 gauge was as expected by the pilot and within the normal green range. The flight to the heliport lasted about three minutes and the pilot shut the engine down after landing.

1.4 The scenic flight was planned to last about six minutes and to return to the heliport. The helicopter took-off normally to the south-west, turned left, climbed to an altitude of about 2800 feet and proceeded left around the Mount. During the three minute cruise phase of the flight, with around 80% engine torque selected, the pilot noticed the T4 gauge was showing a higher than usual MGT which was near the top of the green range, i.e. about 700°C.

1.5 When the helicopter passed abeam the heliport prior to the completion of the flight, the pilot lowered the collective lever to near the bottom of its travel and commenced a descending left turn to position the helicopter for a landing on the heliport.

1.6 As the pilot began raising the collective control lever at around 1800 feet amsl to arrest the descent he did not hear the usual engine sound associated with a power increase. Instead he heard a decrease in the rotor revolutions per minute (rrpm). He looked at the single needle rrpm gauge and saw that the rrpm was decaying quickly. At the same time he heard unusual noises coming from the engine area.

1.7 The pilot immediately lowered the collective lever and entered autorotation. At the same time he transmitted a distress call to Rotorua Tower, and the aerodrome controller notified the Police and emergency services.

1.8 The only area available to the pilot for an emergency landing, in the limited time of around ten seconds before ground contact, was a grassy paddock that sloped away from the direction of travel of the helicopter. During the autorotational landing the helicopter touched down heavily and skidded about 38 m down slope but remained upright. The helicopter sustained damage to its skid landing gear, tail boom and main rotor blades during the landing sequence. No fire occurred.

1.9 Nobody was injured during the landing. The pilot secured the helicopter and evacuated the passengers. A short time later the pilot of another helicopter landed to check on the situation and about ten minutes after the emergency landing the Police arrived at the site.

1.10 The pilot did not recall hearing the low rrpm audio alarm sounding during the autorotational landing, even though he said he believed the rrpm reduced to a level low enough to have activated the alarm. After securing the helicopter he tested the low rrpm audio alarm system and found it functioned normally.

1.11 The pilot opened the engine cowls to inspect the engine visually and noticed that the air pressure accumulator, normally fitted to the $P_r$ pneumatic line between the power turbine governor and the fuel control unit, was lying loose on the engine deck.

1.12 Subsequent further external examination of the engine showed also that the B nut that secured the $P_y$ pneumatic line from the fuel control unit to the power turbine overspeed governor was finger tight.

1.13 Apart from the higher than normal MGT during cruise the pilot did not notice anything untoward such as an engine chip light, engine or rotor overspeed or other warning signals. The first indication he had of an engine power loss was during application of collective control to arrest the descent for landing.

1.14 The pilot checked the normal functioning of the engine chip detection system prior to the flight. Each Thursday the engine chip plug was removed and physically inspected. No metallic debris was noticed on the plug during the last inspection.

**Pilot information**

1.15 The pilot held a helicopter Commercial Pilot Licence with a B category instructor rating. His Class 1 medical certificate was valid until 16 June 1998 with no restrictions.

1.16 The pilot gained his AS350D helicopter type rating in September 1995. He also held ratings for Hughes 269 and 369, Bell 206 and Robinson R22 helicopter types.

1.17 On 11 May 1997 the pilot had completed a biennial flight review, Regulation 76 check and renewed his instructor rating.

1.18 During the 90 days before the accident the pilot had flown 56 hours including 36 hours in ZK-HKU. He had a total of 2606 helicopter flying hours including about 250 hours on the AS350D.

1.19 The pilot was employed by the operator in June 1995 and based at Rotorua from that time. He had been off duty the day before the accident. On the day of the accident he started work at around 0830 hours, the usual starting time.

**ZK-HKU**

1.20 The helicopter had been based at Rotorua for the past three years and during that time it was flown by two pilots, the operator's Rotorua base manager and the pilot on the accident flight. They reported that nothing unusual was noted with the helicopter engine or its performance, until the day before the accident. They said that the MGT had never been a limiting factor as maximum engine torque was always reached before any engine temperature limit.

1.21 The helicopter was approved to carry out air transport operations and was used mainly for carrying passengers as well as some occasional lifting and general helicopter work. Occasionally the helicopter was flown to White Island, an active volcano some 48 km from Whakatane in the Bay of Plenty, and landed on a dust free heliport. Normally engine compressor water rinses were only carried out after returning from White Island.

1.22 The pilot said he believed that during cruise at about 80% to 85% engine torque the MGT was usually around 650°C, some 70°C below the top of the green range on the T4 gauge.

1.23 On Saturday 18 April, the day before the accident, the manager noticed fluctuations in the engine MGT on the T4 gauge with the fluctuations in temperature exceeding 20°C. On occasion he had to reduce torque to less than 80% to keep the MGT within the green range. He thought it was a T4 gauge or engine thermocouple problem as the T4 needle occasionally indicated normal temperatures, but would rise again and then lower when power was reduced.

1.24 The manager telephoned the operator's maintenance company and discussed the problem with the engineering foreman, before flying the helicopter to Ardmore for the foreman to inspect the engine. During the flight to Ardmore the problem persisted but the gas producer speed remained normal.

1.25 At Ardmore the foreman verified the accuracy of the T4 readings, as best he could on a hot engine. He said the maintenance company had experience of T4 gauges showing intermittent readings on three previous occasions, and he could not be "absolutely sure" that the indicator may not be at fault. He verified that all of the engine thermocouples were probably functioning correctly. He checked the inlet airflow modulator linkage and modulation ring for correct operation. He advised that in the past the maintenance company had experienced problems with sticking modulator rings on the LTS101 engine in ZK-HKU disrupting airflow into the engine, which resulted in higher than usual T4 readings.

1.26 The foreman found the modulator was not operating the flow fence linearly. He lubricated the linkages and cycled the modulator several times ensuring that it worked properly. He said he believed that a sticking or erratic modulator was the cause of the fluctuating MGT seen on the T4 gauge. An engine flight test was carried out following the rectification, and the foreman said the T4 gauge readings did not fluctuate and that the MGT had lowered to about normal during the test. The manager said there was a decrease in the MGT of more than 20°C. A power assurance check was not carried out.

1.27 The foreman and the manager were satisfied that the problem had probably been rectified and was caused by a sticking modulator and a possible incorrect temperature reading. The foreman released the helicopter back into service with the proviso that the manager was to monitor the MGT and advise the foreman if the problem recurred.

1.28 The manager flew the helicopter back to Rotorua the same day. The MGT began to fluctuate again toward the end of the flight but the manager did not inform the foreman as requested. The manager said he did not inform the foreman as the symptoms were the same and that they had been identified as being not critical to the safe operation of the engine. The manager briefed the accident pilot about the problem after returning to Rotorua, advising him that the helicopter was serviceable but to monitor the MGT.

**The helicopter engine**

1.29 The engine fitted to ZK-HKU was an AlliedSignal LTS101-600A3, serial number LE-43211CE.

1.30 The operator purchased the helicopter, including its engine, from Petroleum Helicopters Incorporated in the United States. After purchase, the operator had Petroleum Helicopters' maintenance company carry out a 1200 hour inspection on the engine, including a hot section inspection, before delivering the engine to the operator. The inspection was completed on 13 January 1995, at which time the engine had accumulated 5907.9 hours and 17 399.27 cycles. In addition to the inspection the engine was upgraded and all relevant Airworthiness Directives and engine manufactures' Service Bulletins (SB) were complied with.

1.31 The engine logbook showed that the following new components were fitted to the power turbine module (PTM) during the 1200 hour inspection: a gas producer (GP) turbine shroud; MGT leads; number two bearing outer race; oil feed ring; retainer plate and shim; fuel manifold.

1.32 During September 1995, in New Zealand, the operator had the PTM removed and the power turbine (PT) disc replaced with another disc due to excessive PT blade shift. SBs LT101-72-50-0152 and 0153 which related to the PT disc were also carried out.

1.33 In December 1995 the PT disc was removed and returned to the manufacturer "for warranty". Another disc was installed in the engine. An engine vibration check was performed and found satisfactory.

1.34 During December 1996 the PT disc was removed for excessive blade shift and warranty replacement by the engine manufacturer, and numbers two and three bearings were replaced to the latest specification. An engine vibration check was performed and found to be satisfactory. This was the last engine vibration check carried out.

1.35 A 100 hour inspection of the engine was recorded as having been carried out during the last PT disc replacement in December 1996. At that time the engine had accumulated a total of 6423.9 hours, and 516 hours since the 1200 hour inspection.

1.36 The last scheduled inspection of the engine was a 100 hour inspection completed on 25 February 1998 at 6817.4 engine hours and 1719 cycles. The next 100 hour inspection was due on 23 August 1998 or 6917.4 engine hours.

1.37 At the time of the accident the engine had accumulated a total of 6851.8 hours and 1785 cycles, including 943.9 hours since the last hot section inspection.

### Engine maintenance

1.38 The operator's Operations Maintenance Manual (OMM) approved by the Civil Aviation Authority (CAA) required the engine to be maintained in accordance with its manufacturer's maintenance recommendations, and that maintenance would be carried out by Farm Helicopters Limited (the maintenance company), the operator's parent company.

1.39 The operator's maintenance controller was also the chief engineer for the maintenance company. He was approved for both roles by the CAA in accordance with Civil Aviation legislation, and named in the operator's OMM.

1.40 Apart from daily and pre-flight inspections of the engine, the engine manufacturer required scheduled periodic 50, 100, 150, 300, 600 and 1200 hour inspections to be carried out at prescribed intervals, including a hot section inspection every 600 or 1200 hours depending upon engine configuration. The engine fitted to ZK-HKU required a hot section inspection every 1200 hours. The engine manufacturer required daily compressor water rinses to remove internal salt deposits from the engine. The manufacturer's maintenance manual for a similar engine, the LTS101-750, required daily compressor water rinses only when operating in salt environments. The operator opted to advise its pilots to carry out daily compressor water rinses only if flying in a salt atmosphere or in other conditions that may cause compressor contamination or sulphidation (sulphide deposit).

1.41 The maintenance company computer generated maintenance records recorded that the periodic inspections carried out on the engine and airframe were the 100 hour inspections. There was no record of other periodic inspections having been carried out. The maintenance company however considered that the few additional inspection items required by the 300 hour and 600 hour engine inspections were carried out when the PT discs were replaced and during the 100 hour inspections, although the worksheets for the 100 hour engine inspection did not specifically include items from the 300 hour and 600 hour inspections.

1.42 The 50 hour inspection was a minor inspection incorporating the daily inspection requirements usually carried out by pilots plus a fuel filter differential pressure check which could be adapted to specific operating environments. The 150 hour inspection called for the daily, 50 and 100 hour inspection requirements to be performed.

1.43 Any additional inspection items called for by the daily, 50, 150, 300 and 600 hour inspections probably had no direct bearing on the engine failure.

1.44 The engine manufacturer required operators to select one of two maintenance programme options and to adhere strictly to the applicable recommendations.

> A "Hard-Time" programme which assigned a conventional engine and module time between overhaul based on engine operating hours; or
>
> an "On-Condition" programme that allowed the engine and its modules to remain in operation for as long as inspection and checks indicated that the engine was serviceable.

1.45 The operator selected the "On-Condition" maintenance programme.

1.46 The "On-Condition" programme required a "premonitoring" check list to be completed and the establishment of a baseline MGT and trend points. Amongst the ongoing maintenance requirements, operators were required to follow a recommended oil analysis programme and the manufacturer's engine performance trend monitoring procedures.

1.47 The engine performance trend monitoring procedures required operators to record and maintain a log of all power assurance check parameters utilising the procedures found in the helicopter flight manual. The log was to be retained with the engine log book for review prior to engine maintenance. Alternatively an operator could record the "trend [of the] power assurance margin" detailed in the flight manual. The engine manufacturer recommended that trend points be taken at regular intervals not exceeding 50 engine operating hours.

1.48 The engine manufacturer required maintenance action if either the operating MGT margin was less than zero or had deteriorated more than 10°C since the last power assurance check.

1.49 The chief engineer advised that a "premonitoring" check list, baseline MGT and trend points had not been established for the engine and that trend power assurance checks were not routinely carried out and recorded for review. He said there was no need to have the checks carried out and recorded since pilots routinely flew the same helicopters and monitored their engine performance, and should pick up any changes from the usual parameters.

1.50 The engineering foreman advised that following each routine maintenance inspection a power assurance check was carried out to ensure that engine performance was within the required margins. These results however were not documented.

1.51 An oil analysis programme was followed by the operator. No adverse test results had been found, including the results from the last oil sample which was taken during the most recent 100 hour inspection.

**Engine examination**

1.52 The engine was returned to the manufacturer in the United States for examination, which was carried out under the supervision of the Commission and the National Transportation Safety Board. The examination revealed that internal mechanical failure of the engine had occurred, which resulted in a sudden total power loss.

1.53 There was extensive damage to the single crystal GP rotor disc turbine blades. Fourteen of the 40 blades were missing trailing edge or full chord blade sections and there were eroded areas and nicks on the leading edges of all of the blades. The tangent angle (blade twist) of fifteen blades was measured and found to be consistent with normal operation. There was rotational scoring of around 0.075 inches on all of the remaining blade tips with corresponding rotational score marks on the internal diameter of the GP turbine rotor shroud cylinder which fitted around the GP rotor disc turbine blades.

1.54 During normal operation of the engine the GP turbine blades rotated inside the GP turbine rotor shroud with minimal clearance or light rubbing between the blade tips and the inner diameter of the shroud (see Figures 1a and 1b).

1.55 No evidence of sulphidation was observed on the GP turbine blades. Material analysis of the blades suggested stress rupture (blade creep) fracture had occurred. There was no incipient melting between the blade material and its coating.

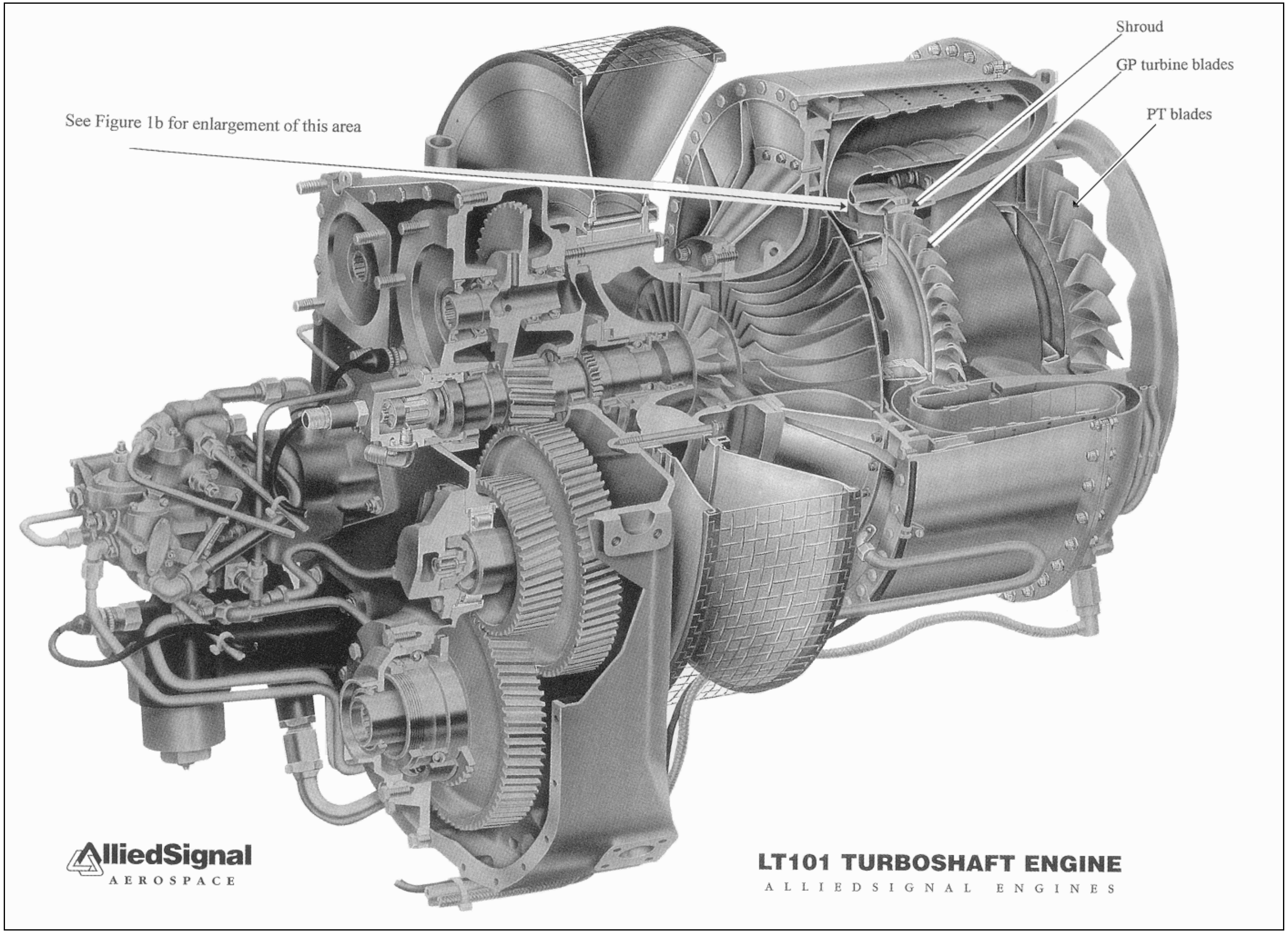


**Figure 1a**
**LTS 101 engine**

1.56 The GP turbine nozzle assembly was found intact, but 28 of the 29 vanes displayed some thermal trailing edge damage. Nineteen cracks with a maximum length of 0.75 inches were found on the inner combustor liner shroud.

1.57 The GP turbine rotor shroud cylinder including its mount and support section had fractured into a number of pieces. Material analysis showed that the shroud had fractured due to overload and that the dimensions, material and hardness were to the correct specifications. Rotational score marks through 360 degrees on the inside diameter of the shroud cylinder corresponded with the rotational scoring on all the remaining GP turbine blade tips.

1.58 Fitted around the outside diameter of the GP turbine rotor shroud were two shroud sealing rings The sealing rings were designed to fit firmly around the shroud to prevent excessive leakage of compressed air from around the outside of the combustion chamber past the shroud to the GP turbine blades. During normal operation of the engine the sealing rings rub against the shroud and eventually wear (see figure 1b).

1.59 Both GP shroud sealing rings, although intact, were worn excessively. The wear was more than 0.060 inches in diameter in excess of the maximum wear allowed by the manufacturer. Material analysis showed that the material and its hardness were to the correct specification and that the wear was characteristic of erosion over time. No sulphidation was observed on the sealing rings.

1.60 The combustion liner assembly dome was cracked circumferentially in three places with the maximum length approximately 2.5 inches. The inner wall was similarly cracked between cooling holes with the maximum crack length about 1.5 inches. All of the four combustion liner mounting brackets had separated from the liner near where the brackets were brazed to the liner. Material analysis showed that one separation surface on each of two of the brackets had fatigue cracking. There were carbon deposits and erosion on the outer wall cooling skirt adjacent to seven of the eight fuel nozzle locations.

1.61 The four combustor mounting bolts were worn on the combustor mount bracket pilot surfaces, and material analysis showed that each of the mounting bolts exhibited fret-like wear around the entire circumference of the bolt tips. The material and hardness of the bolts were to the correct specification.

1.62 The combustion chamber curl (outer transition liner) was intact, but there were nine radial cracks extending in both directions from the cooling holes at the inner diameter. The maximum crack length was about one inch. Fretting had occurred over 360 degrees on the lower surface of the inner flange with corresponding fretting on the GP nozzle forward pilot lip.

1.63 The PT nozzle was found intact with nicks on the trailing edges of the suction side of all the 46 vanes. Two rotational metal smears on the PT nozzle shroud corresponded with tip rubs on the PT rotor turbine blades.

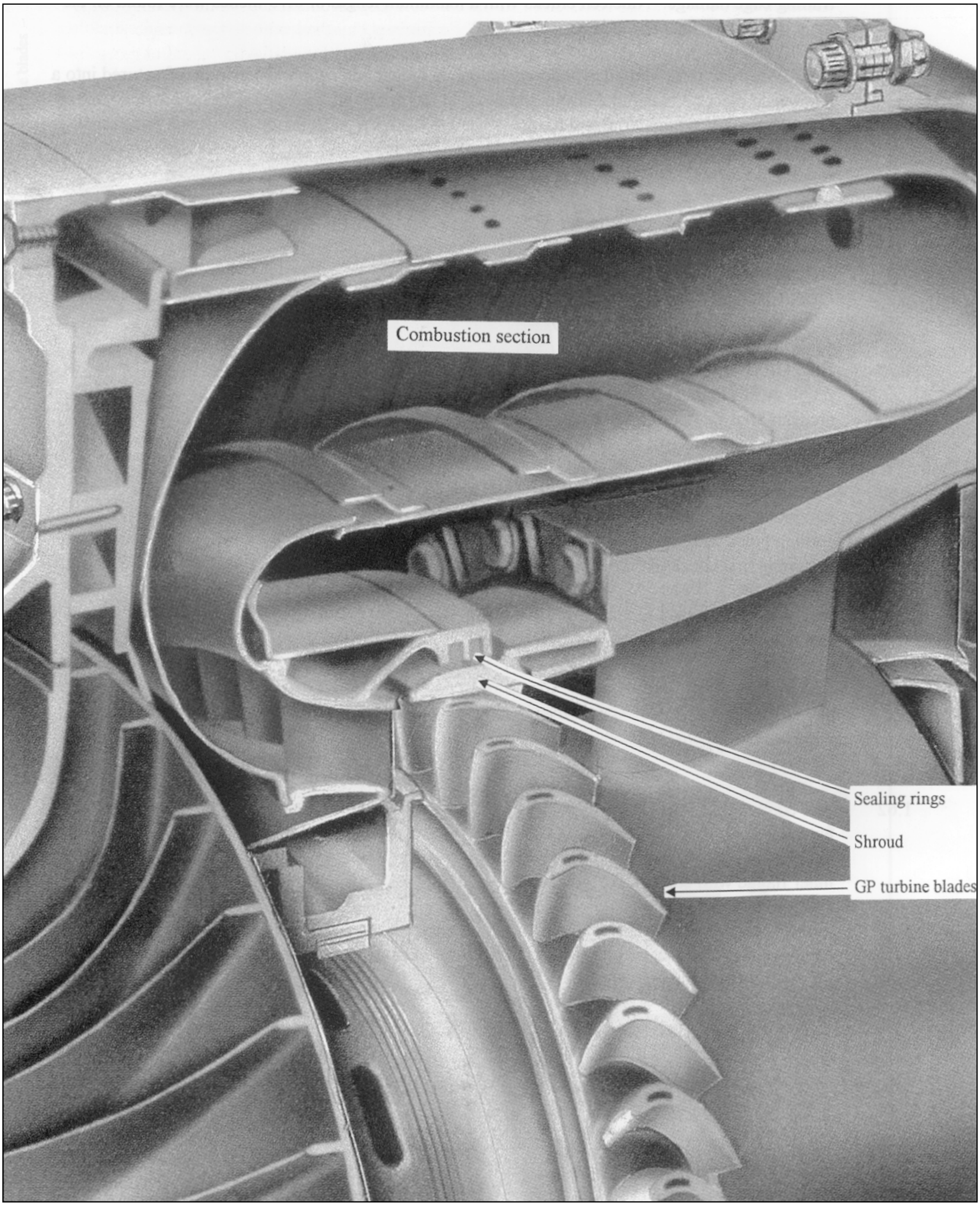


**Figure 1b**
**LT101 sectional enlargement**

1.64 The PT rotor assembly was intact and the speed indicator plug was attached and undamaged. Leading edge damage had occurred to all the PT rotor disc turbine blades in the vicinity of the blade tips. Material analysis of the PT blades determined that the leading edge damage was caused by overload resulting from secondary impact damage. PT blade displacement met the required specifications.

1.65 The number two roller bearing elements were smeared into their cage with corresponding rotational scoring on the bearing outer race. The inner race and cage were discoloured. Number three bearing aft inner race was fused to the PT rotor shaft, and the bearing elements were discoloured and roughened. The bearing cage was undamaged. The examination revealed that the damage to both bearings was secondary, resulting from the mechanical disruption of the engine and subsequent high radial loads on the rotating system.

1.66 The engine oil supply system was serviceable.

1.67 The fuel control system, including the fuel manifold, functioned acceptably. During the functional testing, the effects of the loss of the $P_r$ accumulator and any bleed off of $P_y$ pressure were duplicated. The tests showed that a sudden loss of $P_r$ pressure could result in an increase of fuel flow to the "maximum throttle [flow] stop position fuel flow", but any increase would not have caused the engine damage observed. Any bleed off of $P_y$ pressure immediately reduced the fuel flow. The engine overspeed protection systems all functioned acceptably. Engine component measurement and examination did not reveal any evidence of engine operation in excess of permitted rotational speeds.

1.68 Inspection of the $P_r$ accumulator and $P_y$ line B nuts and their fittings did not reveal anything that could have contributed to their loosening.

1.69 The engine chip detector was undamaged and contained a large amount of metallic bearing material.

1.70 Testing and examination of the engine MGT system found that it was providing accurate temperature measurement signals.

1.71 The ignitor plugs were undamaged.

1.72 Some rotational damage occurred to the compressor rotor spool and compressor shrouds as a result of the failure sequence.

1.73 No records were obtainable from the former engine operator's maintenance company about the condition of the GP turbine rotor shroud sealing rings, or if they were replaced, during the last hot section inspection of the engine. However, the engine logbook showed that the GP turbine rotor shroud had been replaced. The manufacturer advised that it would have been normal practice to replace the sealing rings at the time the shroud was replaced.

1.74 The engine manufacturer's Maintenance Manual specified the inspection requirements for the GP turbine rotor shroud sealing rings and the dimensional inspection limits and condition necessary for continued operation. Revisions to the Maintenance Manual on 15 May 1998 amended the sealing ring dimensional inspection limits. The revisions were made to preclude excessive GP blade tip rub. The Maintenance Manual did not specifically require the sealing rings to be replaced or measured as part of the scheduled maintenance, or refer to excessive sealing ring wear being associated with high MGTs and the possibility of engine failure.

1.75 The manufacturer advised that there had been past instances of GP turbine rotor shroud sealing rings wearing excessively during service. No conclusions had been reached explaining the excessive wear. In the instances reported to the manufacturer, degrading or varying engine performance and rising or varying MGTs, detected by power assurance trend checks, alerted the operators to inspect the sealing rings. Other engine overhaul facilities have reported instances of sealing ring wear similar to that found in the engine fitted to ZK-HKU.

1.76 The manufacturer said that the only effective method of detecting excessive sealing ring wear during normal operation of the engine was to follow the power assurance trend checks detailed in, and required by, the Maintenance Manual. The manufacturer advised that it is planning to review and revise the performance trend monitoring guidelines which are currently published.

**Helicopter maintenance and operator surveillance**

1.77 The maintenance company, under contract to the operator, maintained the operator's helicopter fleet as a maintenance service provider in accordance with Civil Aviation Rules (CAR) Part 43. This allowed the maintenance company to provide maintenance services for operators of:

- air transport aircraft less than 5700 kg maximum certified take off weight or having nine or less passenger seats,
- non-air transport commercial aircraft,
- private aircraft.

The maintenance company was approved as an aircraft maintenance organisation under CAR Part 145 for the maintenance of some aircraft components.

1.78 There was no requirement for persons or companies providing maintenance services in accordance with CAR Part 43 to be certificated, and consequently to have those services audited by the CAA directly. The quality of the maintenance carried out by such maintenance service providers could however be scrutinised during CAA audits of operators utilising their services. The component maintenance aspects of the maintenance company approved under CAR Part 145 was audited by the CAA.

1.79 The three most recent CAA audits of the operator occurred during March 1996, March 1997 and March 1998. The audits sampled some aspects of the operator's helicopter maintenance systems which included; how maintenance was controlled, the computer based maintenance programme, defect control and rectification, component records, the implementation of Airworthiness Directives and inspection of helicopters.

1.80 During the last audit one month before the accident ZK-HKU and its technical log were inspected. The findings recorded against the helicopter were that it did not have exit markings on the inside and outside of its entrance doors and that its technical log did not have the "date of maintenance review" written in the appropriate column. The last audit also consisted of checking the operator's maintenance systems and how the maintenance of the operator's fleet of aircraft was controlled. The computer-based logbook and maintenance record system was briefly reviewed. The audit report stated that it was not possible to carry out an audit against the operator's OMM as it was "out-of-date", and as a result no maintenance reviews were carried out on any of the operator's aircraft. The audit report stated the "out-of-date" OMM was due to the operator awaiting a reply from CAA on OMM amendments submitted in October 1996, as the operator had not supplied sufficient information to CAA about its computer based maintenance record system or deleted references to obsolete requirements. The audit report called for the manual to be amended and recommended a further audit be scheduled to carry out a maintenance review of the operator's aircraft.

1.81 CAA advised that the situation concerning the operator's OMM amendments was "clouded" due to transitional arrangements with regard to re-certification under the new CARs, and that the operator subsequently submitted amendments to its OMM which have been processed. CAA also advised that a maintenance review of the operator's aircraft has taken place and as result no further audit has been scheduled.

1.82 The audit records from March 1996 to March 1998 did not refer to the non-establishment of a "premonitoring" check list, baseline MGT and trend points, or that power assurance trend checks were not being completed and recorded as specified by the LTS101 engine manufacturer for "on-condition" maintenance. Neither did the audit reports mention the absence of daily compressor water rinses, or disclose that of all the periodic inspections the 100 hour inspections were the only ones recorded as having been carried out.

1.83 CAA advised that the operator's maintenance omissions would not necessarily be identified during audits of an operator's maintenance systems since they were at a level of detail not normally covered during audits, and that more detailed sampling would have been needed to identify such omissions. If particular aspects of an operator's procedures raised concern during an audit then more comprehensive sampling may then be carried out which could detect such omissions.

## 2. Analysis

2.1 The engine examination revealed that, during normal in-flight operation, the engine suffered a sudden total power loss due to internal mechanical disruption, precipitated by excessively worn GP turbine rotor shroud sealing rings.

2.2 The wear in the GP turbine rotor shroud sealing rings exceeded, by a significant amount, the maximum wear permitted by the manufacturer. The excessive sealing ring wear resulted in excess air leaking from around the combustion chamber over the shroud to the GP turbine blades, which cooled the shroud and caused it to contract, reducing the clearance between the GP turbine blade tips and the shroud.

2.3 Heavy GP blade tip rub and increased turbine temperatures resulted. The damage to the combustor outer curl and GP nozzle was indicative of excessive temperatures.

2.4 The single crystal GP rotor disc turbine blade separations were characteristic of stress rupture fracture mode. The average tangent angle measured on the GP turbine blades and the lack of other characteristic microstructure features suggested that the stress rupture damage occurred over a relatively short time period. Evidence analysis suggested the temperatures in the vicinity of the blades were probably below 2190° Fahrenheit (1199°C) but above 1900° Fahrenheit (1038°C).

2.5 All of the available evidence, including the check the day before the engine failure, supported the conclusion that the engine MGT system was providing accurate temperature measurement signals.

2.6 The separations of the combustor liner brackets, wear on the combustor mounting bolts and damage to the number two bearing were indicative of excessive engine vibration such as that which can result from heavy GP turbine blade rub.

2.7 Tests showed that the separation of the $P_r$ accumulator from its fitting could result in an increase in fuel flow, but that any increase would have been limited to the maximum allowed by the "fuel control maximum throttle [flow] stop". Any tendency for the engine to overspeed should have been prevented by the serviceable overspeed devices, and examination of the engine showed no evidence to suggest engine operation in excess of permitted rotational speeds. The pilot did not report an engine overspeed or any undemanded increase in power.

2.8 There was insufficient evidence to determine whether the separation of the accumulator contributed to the incident, but test results showed that the separation would not have caused the engine damage observed.

2.9 The separation of the $P_r$ accumulator from its fitting probably occurred during the failure of the engine or during the emergency landing. The loosening of the accumulator and $P_y$ line B nuts can be attributed to migratory vibrations resulting from the heavy GP turbine blade tip rub.

2.10 There were no other engine control system discrepancies identified which could have interfered with normal engine operation.

2.11 The following summarises the most likely chain of events leading to the failure:

- excessive leakage of air over the GP turbine rotor shroud to the GP turbine blades, due to the badly worn shroud sealing rings, resulted in contraction of the GP shroud and reduced GP turbine blade tip clearance and increased turbine temperature,
- the reduced GP turbine blade tip clearance resulted in heavy GP turbine blade rub, which caused excessive engine vibration and further increased turbine temperatures,
- the increased turbine temperatures resulted in thermal damage observed to the combustion outer curl and GP turbine nozzle, and stress rupture fractures of the GP turbine blades,
- stress rupture fracture of the GP turbine blades resulted in increased vibration, damaging the number two bearing to the point where the aft gas generator spool became unsupported,
- the loss of support for the aft gas generator spool resulted in fracture of the GP turbine rotor shroud and contact between rotating and static turbine components, followed by engine deceleration and loss of power to the helicopter.

2.12 Although the engine failure sequence probably occurred over a relatively short period of time, some symptoms of impending engine failure were evident at least the day before and on the day of the accident. These symptoms included an MGT rise of some 50°C to 70°C from normal during cruise flight.

2.13 The symptoms as reported to the engineering foreman however, and those seen during the test flight, did not lead necessarily to a diagnosis of excessively worn sealing rings or an impending engine failure. Consequently the foreman did not diagnose that the engine problems experienced on the day before the accident were indicative of excessively worn GP turbine rotor shroud sealing rings, and that an engine failure was imminent.

2.14 The MGT fluctuations were likely to have resulted from the sealing ring wear having reached a critical state, thus causing the rings to stick in their housing and seal against the shroud intermittently.

2.15 Had the base manager informed the engineering foreman, as requested, that the fluctuating MGT indications recurred on the return flight to Rotorua, the engineering foreman may have made further detailed examination of the engine. Such examination should have disclosed the worn sealing rings and averted the accident.

2.16 The reason why nothing untoward was noticed with the engine until the day before the engine failure was not established, but the excessive sealing ring wear was likely to have occurred over some period of time before the failure. Had the operator followed the manufacturer's required engine performance trend monitoring procedures, variations in or a gradual degradation of engine performance should have been detected, which should have alerted the operator to examine the sealing rings for wear.

2.17 Even though the pilots routinely monitored the normal engine performance they did not have a baseline MGT and trend points established as a yard stick by which they could gauge any variations in engine performance. Consequently the pilots were unlikely to detect gradual or subtle changes in engine performance over a given time.

2.18 The unusual engine vibrations resulting from the GP blade tip rub would have been at such a frequency that pilots would have been unlikely to detect them.

2.19 Proper engine performance trend monitoring was essential to detect excessive GP turbine rotor shroud sealing ring wear, as there was no mandatory requirement to replace or measure the sealing rings during scheduled maintenance.

2.20 Although the CAA audit process involved a sampling technique which looked at different aspects of the operator's helicopter maintenance systems, and the last audit was restricted due to the "out-of-date" OMM, it missed some significant items after three consecutive annual audits. In this case a more comprehensive audit programme could have detected the omission by the maintenance service provider to follow all the requirements specified by the engine manufacturer and brought them to the attention of the operator for rectification. Despite this it was the responsibility of the operator, and in its best interests, to ensure that the engine manufacturer's maintenance requirements were followed carefully.

2.21 The operator's maintenance controller should have detected the omission by the maintenance company to follow all of the manufacturers requirements for engine maintenance. However, as he was also the maintenance company's chief engineer, he was not in the best position to critically review the quality of maintenance provided by the maintenance company.

2.22 The pilot's prompt action and the standard of his autorotational landing onto difficult terrain, in the short time available to him after the engine failed, demonstrated the importance of training pilots to handle emergency situations competently, to act as a last line of defence against the consequences of an in-flight aircraft systems failure.

## 3. Findings

Findings and any safety recommendations are listed in order of development and not in order of priority.

3.1 The pilot was appropriately licensed and fit to conduct the flight.

3.2 The helicopter was approved for the type of operation being conducted.

3.3 The helicopter records indicated it was airworthy and operating within the required maintenance period.

3.4 An internal mechanical disruption of the helicopter engine was precipitated by excessively worn GP turbine rotor shroud sealing rings, and resulted in an in-flight sudden total power loss.

3.5 The operator was unaware of the worn GP turbine shroud sealing rings because it did not follow all of the required maintenance procedures.

3.6 The accumulator separation probably occurred during the failure of the engine or the emergency landing and is unlikely to have contributed to the engine failure.

3.7 The engine had not been maintained in accordance with all the applicable requirements specified by the manufacturer, as required by the OMM.

3.8 The absence of a specific requirement to replace or measure the GP shroud sealing rings for wear during scheduled maintenance should not have been a factor had the requirements of the OMM been followed.

3.9 The pilots who routinely flew the helicopter and monitored its performance in general terms could not be expected to have detected anything untoward with the engine, until the day before the accident.

3.10 Had the operator adhered to the requirements for engine performance trend monitoring it is probable the excessive GP shroud sealing ring wear would have been detected and rectified before the engine failure occurred.

3.11 The CAA audit sampling system used to audit the operator's maintenance systems was not sufficient to enable CAA to detect over a three year period that the maintenance company was not following all of the applicable maintenance requirements.

3.12 The limited scope of the CAA audit system highlights the importance of operators taking responsibility for detecting maintenance omissions through their own internal monitoring system.

3.13 The operator did not meet its responsibility for ensuring that all of the applicable engine maintenance requirements, including the engine performance trend monitoring procedures, were being observed.

3.14 The approval for the maintenance company's chief engineer to also act as the operator's maintenance controller was in accordance with Civil Aviation legislation.

3.15 The Civil Aviation legislation which allowed the chief engineer to also act as the operator's maintenance controller, without additional controls being imposed, was not appropriate.

3.16 The pilot's training and experience resulted in an autorotational landing which, as a last line of defence, prevented injury to the helicopter occupants.

3.17 The active and latent failures which combined to bring about the accident included:

**Active failures**

- Continued operation of the engine after it had displayed symptoms of impending failure.
- The excessively worn GP shroud sealing rings.
- The non-detection of the worn sealing rings.
- The engineering foreman not being advised that the engine problem had recurred.

**Latent failures**

- The operator not ensuring that all of the required manufacturer's maintenance procedures were being followed, especially the engine performance trend monitoring procedures.

## 4. Safety Recommendations

4.1 On 29 May 1998 the Commission recommended to the Director of Civil Aviation that he:

4.1.1 advise all New Zealand operators of the AlliedSignal LTS101 engine to inspect and check tighten each B nut that secures the $P_r$ and $P_g$ accumulators to their respective pressure line, inspect and check tighten the B nut that secures the $P_y$ line to the overspeed governor, and to report to the CAA any instances of loose fittings. (045/98)

4.2 On 3 June 1998 the Director of Civil Aviation responded as follows:

4.2.1 This letter is to advise you that the CAA has already written to all operators of the ASD350 helicopters with the AlliedSignal LTS101 engines, advising them that they should take the actions specified in your Final Safety Recommendation.

4.3 On 27 May 1998 the Commission recommended to AlliedSignal Aerospace:

4.3.1 that it advises all current users of the AlliedSignal LTS101 engine to inspect and check tighten each B nut that secures the $P_r$ and $P_g$ accumulators to their respective pressure line, inspect and check tighten the B nut that secures the $P_y$ line to the overspeed governor, and to report to the manufacturer any instances of loose fittings (046/98) and;

that it reviews the adequacy of the provision for securing the $P_r$ and $P_g$ accumulator B nuts to their respective fitting in their pressure line, on the LTS101 engine. (047/98)

4.4 On 21 August 1998 AlliedSignal Aerospace responded as follows:

4.4.1 AlliedSignal intends to adopt both safety recommendations. To implement recommendation 046/98, a Customer Service Letter (CSL) will be issued informing LTS101 operators and maintenance facilities of the accumulator separation and emphasizing the importance of inspecting this and all pneumatic system connections and lines for proper installation and integrity. This CSL has been drafted, is being reviewed, and is expected to be released by October 30, 1998.

4.4.2 To implement recommendation 047/98, AlliedSignal has reviewed the adequacy of the provision for securing the accumulator to the engine fitting, however, AlliedSignal does not have design authority to make changes to this part. Accordingly, the safety recommendation will be forwarded to both airframe customers and the FAA for their consideration.

4.5 On 7 October 1998 the Commission further recommended to the Director of Civil Aviation that he:

4.5.1 advise all New Zealand operators of the LTS101 engine of the necessity and importance of following the performance trend monitoring procedures specified by the engine manufacturer in order to detect excessive wear of the GP turbine rotor shroud sealing rings (087/98); and

4.5.2 reconsider the decision to continue to approve a person to act as maintenance controller for an operator when that person was also employed by the maintenance service provider contracted to carry out aircraft maintenance for the operator. (088/98).

4.6 On 28 October 1998 the Director of Civil Aviation responded as follows:

4.6.1 In response to Final Safety Recommendation 087/98, the CAA believes that it would be more appropriate to focus on the need for **all** the procedures specified by the manufacturer to be followed, with this event used as an example of the result of failure to take such action. The CAA would implement such corrective action by the publication of a suitable article in Vector, probably within the first quarter of 1999.

4.6.2 In regard to Final Safety Recommendation 088/98, the CAA has already reviewed the practice of the dual role exercised by some individuals. In the changeover to operator certification under Part 119 of the new rules, much more stringent standards are being applied if the air transport operator seeks to have the same person carry out both functions. This operation was being carried out under a certificate issued under the 1953 Civil Aviation Regulations.

There are, in New Zealand, a number of instances where it is impractical to have a person other than the local licensed aircraft maintenance engineer filling the two roles. In such cases, CAA continues to clearly indicate to the industry, both in general material and directly to the relevant individuals, the necessity of fully understanding the significant difference in the two roles and the clear need to be able to make, and to make, decisions appropriate to those roles.

4.7 On 7 October 1998 the Commission recommended to the Managing Director of Marine Helicopters Limited that he:

4.7.1 ensure that all of the requirements specified by the manufacturer for LTS101 engine maintenance, including the performance trend monitoring procedures, are being carried out. (089/98).

4.8 On 30 September 1998 Marine Helicopters Limited responded as follows:

4.8.1 In response to the preliminary safety recommendation we have put in place condition monitoring onto the weekly tech log report and have amended the work sheets to reflect the 300,600,900 and 1200 HR inspection requirements.

4.9 On 10 August 1998 the Commission further recommended to AlliedSignal Aerospace that it:

4.9.1 review the LTS101 engine periodic inspection requirements regarding the GP turbine rotor shroud sealing rings to establish if there is a need for these sealing rings to be replaced or measured as part of the scheduled maintenance. (090/98).

4.10 On 21 August 1998 AlliedSignal responded as follows:

4.10.1 To implement recommendation 090/98, AlliedSignal intends to update the Hot Section Inspection (HSI) requirements specified in the engine Maintenance Manual to clarify which component inspections are required, including the inspection of the GP turbine shroud seal rings. This task has been assigned, and is expected to be complete by 30 October, 1998.

An additional item mentioned in your letter 8 September, 1998, but not the subject of a safety recommendation, were the AlliedSignal requirements for conducting performance trend monitoring. These requirements are also being reviewed, and will be updated.

Approved for publication 3 February 1999

Hon. W P Jeffries
**Chief Commissioner**

## Glossary of abbreviations used in this report

| | |
|---|---|
| amsl | above mean sea level |
| C | Celsius |
| CAA | Civil Aviation Authority |
| CAR | Civil Aviation Rules |
| CSL | Customer Service Letter |
| E | east |
| FAA | Federal Aviation Administration (United States) |
| GP | gas producer |
| kg | kilograms |
| km | kilometres |
| m | metres |
| MGT | measured gas temperature |
| NZST | New Zealand Standard Time (UTC+12 hours) |
| OMM | Operations Maintenance Manual |
| PT | power turbine |
| PTM | power turbine module |
| rrpm | rotor revolutions per minute |
| S | south |
| SB | Service Bulletin |
| UTC | Coordinated Universal Time |