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Undetected Wear of Turbine-shroud Seals Leads to Engine Failure, Emergency Landing

The accident investigation concluded that gradual deterioration of the turbine-rotor-shroud sealing rings was not detected because the helicopter operator did not comply with the manufacturer's engine-performance trend-monitoring procedures.

FSF Editorial Staff

On April 19, 1998, the engine failed in an Aerospatiale AS350D AStar helicopter during approach to land at the Skyline Skyrides heliport in Rotorua, New Zealand. The pilot conducted an autorotational landing on uneven terrain. The helicopter was substantially damaged during the hard landing, but none of the five occupants was hurt.

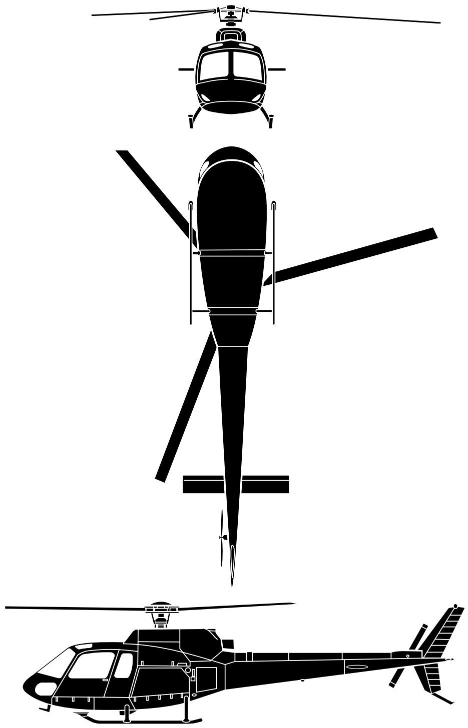
The final report on the accident by the New Zealand Transport Accident Investigation Commission (TAIC) said that the engine failure occurred because air leaking past worn turbine-rotor-shroud sealing rings had cooled the shroud and caused the shroud to contract and contact the turbine-rotor blades.

"Examination of the engine revealed that excessively worn gas-producer [GP] turbine-rotor-shroud sealing rings precipitated internal mechanical failure of the engine, which resulted in a total power loss," said the report. "The worn sealing rings went undetected [because] the manufacturer's required engine-performance trend-monitoring procedures were not being followed."

The helicopter was operated by Marine Helicopters of Rotorua and was maintained by the operator's parent company, Farm Helicopters, in Ardmore, New Zealand. The operator purchased the helicopter in 1995 from Petroleum Helicopters in the United States. Petroleum Helicopters' maintenance company completed a 1,200-hour engine inspection, which included a hot-section inspection, before the helicopter was delivered to Marine Helicopters. At the time of delivery, the helicopter's AlliedSignal LTS101-600A3 turbine engine had accumulated 5,908 service hours.

Marine Helicopters' Operations Maintenance Manual required that the engine be inspected according to the manufacturer's recommendations. The manufacturer recommended that engine inspections be conducted daily, before each flight and at intervals of 50 hours, 100 hours, 150 hours, 300 hours, 600 hours and 1,200 hours. The manufacturer also recommended that daily compressor water rinses be conducted to remove salt deposits from the engine.

The report said that the operator's maintenance records showed that 100-hour engine inspections had been conducted. "There was no record of other periodic inspections having been carried out," said the report. "The maintenance company, however, considered that the few additional inspection items required



Aerospatiale AS350D AStar

The prototype Aerospatiale AS350 light utility helicopter first flew in June 1974 with an AlliedSignal (originally Avco Lycoming) LTS101 turboshaft engine. A second prototype flew in February 1975 with a Turbomeca Arriel turboshaft engine. The Lycoming-powered model was named the AS350C AStar and was marketed only in North America. The AS350C was replaced by the AS350D in 1978. The Turbomeca-powered model was named the AS350B Ecureuil and was marketed in areas outside North America.

The Aerospatiale helicopter division and the MBB (Messerschmitt-Bolkow-Blohm) helicopter division merged in 1992 to form Eurocopter, which currently markets the AStar and Ecureuil.

The AS350D has an LTS101-600A3 engine rated at 615 shaft horsepower (459 kilowatts). The three main-rotor blades are constructed of glass fiber and have stainless-steel leading-edge sheaths. The two tail-rotor blades are constructed of sheet metal and have glass-fiber spars.

The helicopter has accommodations for one pilot and five passengers. Standard seating comprises two bucket seats in the forward cabin and two bench seats in the aft cabin. Steel-tube skids are standard; emergency-flotation landing gear is an option.

Maximum takeoff weight is 4,300 pounds (1,951 kilograms). Maximum rate of climb is 1,575 feet per minute (480 meters per minute). Maximum cruise speed at sea level is 124 knots (230 kilometers per hour). Service ceiling is 15,000 feet. Hovering ceiling in ground effect is 8,200 feet. Hovering ceiling out of ground effect is 5,900 feet. Range with maximum fuel (140 gallons [530 liters]) is 410 nautical miles (759 kilometers).

Source: *Jane's All the World's Aircraft*

by the 300-hour and 600-hour engine inspections were carried out when the PT [power turbine] disks were replaced [in December 1995 and in December 1996] and during the 100-hour inspections, although the work sheet for the 100-hour engine inspection did not specifically include items from the 300-hour and 600-hour inspections.

"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 that could be adapted to specific operating environments. The 150-hour inspection called for the daily, 50[-hour] and 100-hour inspection requirements to be performed."

At the time of the accident, the engine had accumulated 6,852 hours, including 944 hours since the 1,200-hour inspection conducted by Petroleum Helicopters. Thus, a 1,200-hour inspection by Marine Helicopters had not been required before the accident.

The operator had not conducted daily compressor water rinses. The report said, "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 sulfidation (sulfide deposit)." Compressor water rinses normally were conducted only after the helicopter returned from a flight to a volcanic island.

The report said that the operator maintained the engine according to the manufacturer's on-condition maintenance program. "The 'on-condition' program … allowed the engine and its modules to remain in operation for as long as inspection and checks indicated that the engine was serviceable," said the report. "[The program] required a 'premonitoring' checklist to be completed and the establishment of a baseline MGT [measured gas temperature, as indicated by the helicopter's T4 gauge] and [MGT] trend points. Operators were required to follow a recommended oil-analysis program and the manufacturer's engine-performance trend-monitoring procedures."

The trend-monitoring procedures required the operator to conduct power-assurance checks and to maintain records of the power-assurance-check results.

Marine Helicopters' maintenance controller, who also served as chief engineer for Farm Helicopters, said that the operator had not completed a premonitoring checklist and had not established a baseline MGT or MGT trend points. The maintenance controller said that power-assurance checks were not conducted routinely.

The report said, "[The maintenance controller] 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."

The company's engineering foreman said that power-assurance checks were conducted after completion of routine engine maintenance to ensure that engine performance was within required limits. The report said, "These results, however, were not documented."

The operator had followed an oil-analysis program, which included an analysis of an oil sample that was taken from the engine during a 100-hour inspection conducted two months before the accident occurred. None of the results of these analyses indicated that engine maintenance was required.

Audits of the operator had been conducted by the New Zealand Civil Aviation Authority (CAA) in March 1996, March 1997 and March 1998. The report said, "The audits sampled some aspects of the operator's helicopter-maintenance systems that included how maintenance was controlled, the computer-based maintenance [records] program, defect control and rectification, component records, the implementation of airworthiness directives, and inspection of helicopters."

The report said, "The audit records from March 1996 to March 1998 did not refer to the nonestablishment of a 'premonitoring' checklist, baseline MGT and [MGT] 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.

"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 that could detect such omissions."

The helicopter was based in Rotorua for three years and was flown by only two pilots during that time. One pilot was the accident pilot; the other pilot was the operator's Rotorua base manager.

The report said, "[The pilots] 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 [because] maximum engine torque was always reached before any engine temperature limit. … The [accident] pilot said he believed that during cruise at about 80 percent [engine torque] to 85 percent engine torque, the MGT was usually around 650 degrees Celsius [(C); 1,202 degrees Fahrenheit (F)], some 70 degrees C [158 degrees F] below the top of the green range on the T4 gauge."

On the day before the accident, the Rotorua base manager flew the helicopter and noticed MGT fluctuations of more than 20 degrees C (68 degrees F). The report said, "On occasion, he had to reduce torque to less than 80 percent to keep the MGT within the green arc. He thought it was a T4 gauge [problem] or an engine thermocouple problem [because] the T4 needle occasionally indicated normal temperatures but would rise again and then lower when power was reduced."

The Rotorua base manager flew the helicopter to Ardmore, and the engineering foreman inspected the engine. The foreman verified that the T4 gauge and the thermocouples were functioning properly. The report said, "He checked the inlet airflow modulator linkage and modulator ring for correct operation [because] the maintenance company had experienced problems with sticking modulator rings on the LTS101 engine in ZK-HKU [the accident helicopter] disrupting airflow into the engine, which resulted in higher-than-usual T4 readings."

"[The pilots] reported that nothing unusual was noted with the helicopter engine or its performance until the day before the accident."

The foreman found that the modulator was not functioning correctly. He lubricated the linkages and cycled the modulator several times; the modulator functioned correctly when it was cycled. The report said, "[The foreman] 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 degrees C. A power-assurance check was not carried out."

The foreman told the manager to monitor the MGT and to report any recurrence of the problem. The manager then flew the helicopter to Rotorua. The report said, "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 [because] the symptoms were the same and … 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 pilot, 26, was hired by Marine Helicopters in June 1995. He had a commercial helicopter pilot certificate and a flight instructor rating. He had 2,606 flight hours, including approximately 250 flight hours in the AS350D. He earned his AS350D type rating in September 1995 and also had type ratings for the Bell 206, Hughes 269, Hughes 369 and Robinson R22 helicopters.

The pilot began work at 0830 local time on the day of the accident. He conducted a preflight inspection and then flew the helicopter from Rotorua Agrodome to the Skyline Skyrides heliport. The pilot said that MGT was normal during takeoff from Rotorua with 100 percent torque. The flight lasted approximately three minutes.

At 1117, the pilot took off from the Skyline Skyrides heliport to conduct a sightseeing flight around Mount Ngongotaha with four passengers aboard the helicopter. The report said, "During the three-minute cruise phase of the flight, with around 80 percent 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 degrees C [1,292 degrees F]."

The pilot then began a descent from cruise altitude, 2,800 feet, to position the helicopter for a landing at the heliport, which had an elevation of 1,500 feet. The report said, "As the pilot began raising the collective control lever at around 1,800 feet to arrest the descent, he did not hear the usual engine sound associated with a power increase."

Instead, the pilot heard unusual engine noises and the sound of rotor speed decreasing. He lowered the collective-control lever and flew the helicopter in autorotation. During the descent, he transmitted a distress call to Rotorua Tower, which notified the police and emergency medical services.

The report said, "The only area available to the pilot for an emergency landing, in the limited time of around 10 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 meters [125 feet] downslope 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, [and] nobody was injured during the landing."

The pilot secured the helicopter and evacuated the passengers. He then opened the engine cowls to inspect the engine. The report said, "He 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.

"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."

The report said that the separation of the air-pressure accumulator probably occurred during the engine failure or during the emergency landing. "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," said the report.

The report said that the looseness of the B nut probably was the result of vibrations caused by the turbine-rotor blades rubbing against the turbine-rotor shroud before the engine failure occurred.

AlliedSignal conducted a tear-down inspection of the engine under the supervision of TAIC and the U.S. National Transportation Safety Board. The report said, "The examination revealed that internal mechanical failure of the engine had occurred, which resulted in a sudden total power loss."

"The examination revealed that internal mechanical failure of the engine had occurred."

The tear-down inspection revealed that 14 of the 40 GP turbine-disk blades had fractured, and the remaining blades were scored. The turbine-rotor shroud had fractured into a number of pieces. The two turbine-rotor-shroud sealing rings were worn "excessively." The report said, "The wear was more than 0.06 inch [1.52 millimeters] in diameter in excess of the maximum wear allowed by the manufacturer." (Figure 1 shows internal engine components.)

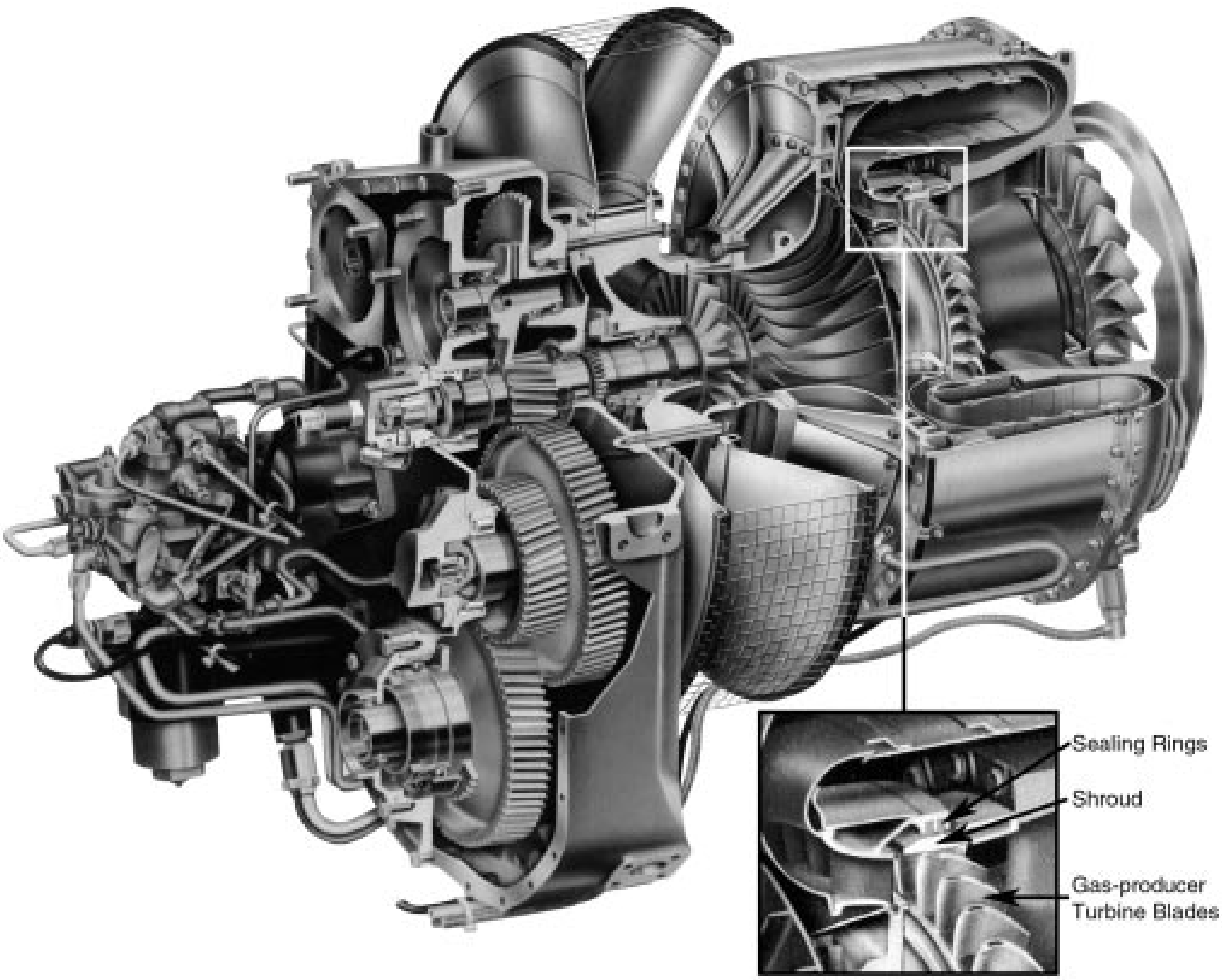
The report said, "During normal operation of the engine, the GP turbine blades rotate inside the GP turbine-rotor shroud with minimal clearance or light rubbing between the blade tips and the inner diameter of the shroud."

The turbine-rotor-shroud sealing rings fit tightly against the shroud to prevent compressed air from leaking from around the outside of the combustion chamber to the turbine section. The report said that the sealing rings eventually wear from rubbing against the shroud.

"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," said the report.

The report said, "Had the operator followed the manufacturer's required engine-performance trend-monitoring procedures, variations in [engine performance] or a gradual degradation

Internal Components of AlliedSignal LTS101 Engine



Source: New Zealand Transport Accident Investigation Commission

Figure 1

of engine performance should have been detected, which should have alerted the operator to examine the sealing rings for wear."

The MGT fluctuations noticed by the Rotorua base manager on the day before the accident were an indication that sealing-ring wear had reached a "critical state." The report said, "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. …

"Proper engine-performance trend monitoring was essential to detect excessive GP turbine-rotor-shroud sealing-ring wear [because] there was no mandatory requirement to replace or measure the sealing rings during scheduled maintenance."

Based on the findings of the accident investigation, TAIC made recommendations to CAA, AlliedSignal Aerospace and Marine Helicopters. The report included responses by CAA, AlliedSignal Aerospace and Marine Helicopters. The recommendations and responses were as follows:

- TAIC said, "[The director of civil aviation should] 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 lines, 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."

– The director of civil aviation said, "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."

- TAIC said, "[AlliedSignal Aerospace should advise] 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 lines, 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; and [review] the adequacy of the provision for securing the P_r and P_g accumulator B nuts to their respective fittings in their pressure lines on the LTS101 engine."

  – AlliedSignal Aerospace said, "AlliedSignal intends to adopt both safety recommendations. … 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 Oct. 30, 1998.

  "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 [U.S. Federal Aviation Administration] for their consideration."

- TAIC said, "[The director of civil aviation should] 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; and 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."

  – The director of civil aviation said, "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* [a magazine published by CAA], probably within the first quarter of 1999.

  "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."

- TAIC said, "[The managing director of Marine Helicopters should] ensure that all of the requirements specified by the manufacturer for LTS101 engine maintenance, including the performance-trend-monitoring procedures, are carried out."

  – Marine Helicopters said, "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 1,200 hour inspection requirements."

- TAIC said, "[AlliedSignal Aerospace should] 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."

  – AlliedSignal Aerospace said, "AlliedSignal intends to update the hot-section-inspection 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 Oct. 30, 1998."♦

Editorial note: This article, except where specifically noted, was based entirely on New Zealand Transport Accident Investigation Commission Aviation Occurrence Report 98-005, *Aerospatiale AS350D, ZK-HKU, in-flight engine failure, Rotorua, 19 April 1998*. The 28-page report contains a photograph and diagrams.

Update

The June 1998 *Accident Prevention*, "Operations and Maintenance Audit Failures Cited as Factors in Two Fatal Accidents," reported on two accidents in New Zealand. One of the accidents occurred about 0130 local time, June 11, 1997, when a Beech 58 Baron (ZK-KVL), a twin-engine airplane, entered a steep spiral dive and struck a wooded slope; the aircraft's only occupant, the pilot, was killed. The Transport Accident Investigation Commission (TAIC), an independent body reporting directly to the New Zealand minister of transport, determined that the pilot probably lost control of the airplane while suffering carbon monoxide poisoning and while encountering severe icing conditions in the vicinity of a convective cell.

The TAIC said that before the ZK-KVL accident occurred, Civil Aviation Authority (CAA) audits of the operator, United Aviation, disclosed several noncompliances (failures to comply with CAA regulations) and several nonconformances (failures to comply with company procedures). The CAA, however, did not take appropriate action to ensure that the operational deficiencies identified by the audits were remedied, and the CAA's failure to take appropriate action contributed to the accident, said the TAIC in its 50-page aviation occurrence report of the accident ("97-012 Beechcraft BE58 Baron, ZK-KVL, in-flight loss of control, 11 June 1997, Tararua Ranges, 21 km south-east of Paraparaumu").

On June 23, 1998, in the wake of the TAIC's published aviation occurrence report, the minister of transport appointed a ministerial committee of inquiry, and on Oct. 20, 1998, the committee published its "Report of the Ministerial Inquiry into Various Aspects of the [New Zealand] Civil Aviation Authority's Performance." In brief, the 86-page report's conclusions are as follows:

- "We consider that the [CAA's] systems for taking action when safety concerns arise, both before and after the accident involving United Aviation's ZK-KVL, are generally well founded. However, while in many respects we consider the system established by the CAA to be well designed and, in essence, world-leading, we have noted room for improvement. In particular, we recommend changes regarding the systems' capacity to track the broad risk profile of companies, better use of all surveillance tools and increased on-site checking of corrective actions;

- "We consider that the statutory powers available to the director of civil aviation are generally adequate to enable him to take appropriate action when safety concerns arise. There are some comparatively minor legislative changes which might be made to give the director added flexibility in the exercise of his powers; [and],

- "With respect to the events leading up to the ZK-KVL accident, we believe that the director acted reasonably and properly on the basis of the information available to him. However, in our judgement, that information available to him was both inadequate and incomplete. Accordingly, we have made various recommendations … which identify ways in which the CAA's surveillance systems could be improved to enable them to deliver better information. This would boost the quality of executive-level decision making within the CAA."

The report said that the inquiry found no compelling reason why the TAIC made a recommendation to the minister of transport, rather than the director of civil aviation as specified by the Civil Aviation Act. (The TAIC recommended that the CAA "implement … a system which will ensure any instances of operator noncompliance and nonconformance … are corrected promptly or sanctions automatically follow.")

The report said, "Such a recommendation to the minister has to be regarded as an extraordinary step and not one to be made without very good cause."

Further, the report said, "We have some difficulty with TAIC's suggestion to the minister … that sanctions should 'automatically follow' if unsafe practices are not corrected promptly. … TAIC's recommendation … is, in the committee's view, constitutionally inappropriate."

The report said that the TAIC accident report contained a chronology of events that "is an incomplete reflection of [the] actions taken [by the CAA] with respect to United Aviation."

"In the committee's view, [the chronology] contains some significant errors, all of which can lead to misconceptions on the part of the reader."

Despite the inquiry's conclusions, the TAIC said that the inquiry was a "weak response to safety issues" and that the TAIC continues to stand by the essence of its aviation occurrence report.♦

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