Australian Government
Australian Transport Safety Bureau

AVIATION SAFETY INVESTIGATION
200105618

On 11 November 2005 a further investigation under section 19DF of the *Air Navigation Act 1920* was commenced into aspects of this accident. This investigation has been completed and a supplementary report 200507077 has been released and is available on the ATSB website.

Beech Aircraft Corporation C90
VH-LQH
Toowoomba, Qld

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Released under the provisions of Section 19CU of Part 2A of the *Air Navigation Act 1920*.

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This report was produced by the Australian Transport Safety Bureau (ATSB), PO Box 967, Civic Square ACT 2608.

Readers are advised that the ATSB investigates for the sole purpose of enhancing safety. Consequently, reports are confined to matters of safety significance and may be misleading if used for any other purpose.

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INTRODUCTION

The Australian Transport Safety Bureau (ATSB) is an operationally independent multi-modal Bureau within the Australian Government Department of Transport and Regional Services. ATSB investigations are independent of regulatory, operator or other external bodies.

In terms of aviation, the ATSB is responsible for investigating accidents, serious incidents, incidents and safety deficiencies involving civil aircraft operations in Australia, as well as participating in overseas investigations of accidents and serious incidents involving Australian civil registered aircraft. The ATSB also conducts investigations and studies of the aviation system to identify underlying factors and trends that have the potential to adversely affect safety. A primary concern is the safety of commercial air transport, with particular regard to fare-paying passenger operations.

Prior to 1 July 2003, the ATSB performed its aviation functions in accordance with provisions of the *Air Navigation Act 1920*, Part 2A. This investigation was conducted under the provisions of that Act because it was the relevant legislation at the time of the accident. Section 19CA of the Act stated that the object of an investigation was to determine the circumstances surrounding any accident, serious incident, incident or safety deficiency to prevent the occurrence of other similar events. The results of these determinations form the basis for safety recommendations and advisory notices, statistical analyses, research, safety studies and ultimately accident prevention programs. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations.

Under the *Air Navigation Act 1920*, it was not the object of an investigation to provide a means to determine blame or liability. However, it should be recognised that an investigation report must include factual material of sufficient weight to support the analysis and conclusions reached. That material will at times contain information reflecting on the performance of individuals and organisations, and how their actions may have contributed to the outcomes of the matter under investigation. At all times the ATSB endeavours to balance the use of material that could imply adverse comment, with the need to properly explain what happened, and why, in a fair and unbiased manner.

ABBREVIATIONS

AAC	Airworthiness Advisory Circular
AD	Airworthiness Directive
AME	aircraft maintenance engineer
ASDR	accelerate stop distance required
ASSP	aviation safety surveillance program
ATSB	Australian Transport Safety Bureau
BASI	Bureau of Air Safety Investigation
C	Celsius
CAAP	Civil Aviation Advisory Publication
CAO(s)	Civil Aviation Order(s)
CAR(s)	Civil Aviation Regulation(s)
CASA	Civil Aviation Safety Authority
CMEIR	command multi-engine instrument rating
EAG	engine analytical guide
ECTM	engine condition trend monitoring
F	Fahrenheit
FAA	Federal Aviation Administration (US)
ft	feet
fpm	feet per minute
ICAO	International Civil Aviation Organization
ITT	inter-turbine temperature
kg	kilograms
km	kilometres
kts	knots (nautical miles per hour)
LAME	licensed aircraft maintenance engineer
m	metre
MH/FH	maintenance hours per flight hour
MOS	Manual of Standards
MTOW	maximum take-off weight
Ng	compressor speed
PWC	Pratt and Whitney Canada
RCA	request for corrective action

RESA	runway end safety area
RPA	Rules and Practices for Aerodromes
RPM	revolutions per minute
RPT	regular public transport
SB	service bulletin
TBO	time between overhaul
TSB	Transportation Safety Board of Canada
TTIS	total time in service
US	United States (of America)
Wf	fuel flow

EXECUTIVE SUMMARY

In common with most transport accidents, this occurrence involved a number of different contributing factors. Although some of these factors were associated with actions of individuals or organisations, it is essential to note that the key objective of an ATSB safety investigation is to identify safety deficiencies or weaknesses in the safety system and to learn how to minimise the risk of future accidents. It is not the purpose or intention of the investigation to apportion blame, or to provide a means of determining liability.

Sequence of events

At about 0836 Eastern Standard Time on 27 November 2001, a Beech Aircraft Corporation King Air C90 aircraft, registered VH-LQH, took off from runway 29 at Toowoomba aerodrome, Queensland for an Instrument Flight Rules charter flight to Goondiwindi, Queensland. On board were the pilot and three passengers.

Just prior to, or at about the time the aircraft became airborne, the left engine failed. A subsequent examination of the left engine found that it probably lost thrust-producing power almost immediately. Following the engine failure, the take-off manoeuvre continued and the aircraft became airborne prior to crashing.

The aircraft was equipped with an automatic propeller feathering system, but the propeller was not feathered at impact. The reason the propeller was not feathered could not be determined. The landing gear was not retracted during the short flight. The right engine was developing significant power at impact.

The aircraft remained airborne for about 20 seconds. The aircraft's flight path was typical of an asymmetric, low speed flight situation, and it is unlikely that the aircraft's speed was ever significantly above the minimum control speed (V_{mca}) of 90 kts. The aircraft manufacturer's specified procedures for responding to an engine failure in LQH stated that the takeoff should be rejected below the 'take-off speed', specified as 100 kts. After control of the aircraft was lost, and as the aircraft was rolling through about 90 degrees left bank, it struck powerlines about 10 m above ground level and about 560 m beyond the end of the runway. It then continued to roll left and impacted the ground inverted in a steep nose-low attitude. An intense fuel-fed fire erupted upon initial impact with the ground. The aircraft was destroyed and all four occupants sustained fatal injuries. The accident was not considered to be survivable due to the impact forces and post-impact fire.

Maintenance-related issues

The central event in this accident was the failure of the left engine, which was the 'critical' engine on the aircraft in terms of aircraft performance considerations. Examination of the left engine showed internal damage that was consistent with the fracture and release of one or more compressor turbine blades into the engine gas path, resulting in a significant reduction in power from the engine. There were no indications that the engine failure was due to manufacturing defects, metal fatigue, foreign object damage during the flight, or the quality or quantity of fuel on board the aircraft. Examination of the compressor turbine blades indicated that they had been exposed to higher than normal operating temperatures in the period leading up to the accident.

The engine failure occurred at 3,556.0 hours since the last overhaul, which was within the 3,600 hours time between overhaul (TBO) specified in the engine manufacturer's service bulletins. However, the aircraft's engines were operating on a life extension to 5,000 hours TBO in accordance with the provisions of the Australian Civil Aviation Safety Authority (CASA) Airworthiness Directive AD/ENG/5 Amendment 7. A requirement of the AD was that, if the engines were operating to a 5,000 hour TBO, they had to be subject to an engine condition trend monitoring (ECTM) program. The pattern of ECTM data from the left engine indicated that a potentially safety-critical problem existed in that engine for several weeks prior to the accident. For a variety of reasons, that evidence was not detected and analysed, nor was appropriate remedial action initiated. Without timely intervention to address the developing engine problem, it was increasingly probable that the aircraft would have an in-flight emergency involving the left engine.

The pattern of evidence suggested that a problem with the efficiency of the cold section of the engine probably led to temperature-related damage to the compressor turbine blades, which probably resulted in the failure of one of those blades. However, some other explanations for the failure, such as a previous hot start leading to or exacerbating the temperature-related damage, could not be discounted.

Apart from issues associated with the left engine, there was no indication of any fault in any aircraft system that may have contributed to the accident. The ECTM data for the right engine suggested that a potential problem had also been developing in the cold section of that engine for a period of time.

The last maintenance of the left engine most probably occurred on 7 June 2001. Based on the requirements of AD/ENG/5, a compressor performance recovery wash was required to be conducted in response to trend monitoring parameter deviations, or at intervals not to exceed 3 months or 220 hours, whichever came first. Had the performance recovery wash been conducted on the left engine at the appropriate time, it may have been effective in removing the source of deterioration in cold section efficiency.

Prior to March 2001, maintenance on the operator's aircraft was conducted by an external maintenance organisation. From March 2001, maintenance was conducted by a newly formed internal maintenance organisation. The ratio of the operator's available maintenance personnel resources relative to the maintenance resources reasonably required, resulted in the operator's chief engineer experiencing a significant workload. In August 2001, the maintenance controller left the operator and the chief engineer took over the maintenance controller responsibilities. His workload increased significantly when he took on these additional responsibilities.

In addition to the level of maintenance resources, the investigation noted that the defences within the operator's maintenance organisation were deficient in a number of other areas. The chief engineer had minimal preparation for his role as maintenance controller. He had also not completed ECTM training, and therefore the operator arranged to send the data to the engine manufacturer's field representative for analysis. However, the ECTM data were not being recorded or submitted for analysis as frequently as required by the engine manufacturer's requirements or AD/ENG/5. In addition, there were deficiencies in the operator's maintenance scheduling processes.

CASA was aware that the chief engineer had not completed ECTM training and that the operator had an arrangement to send ECTM data to the engine manufacturer's field representative for analysis. However, CASA surveillance had not detected any problems with the operator's ECTM program prior to the accident. Following the accident, CASA inspectors conducted a review of the engine condition monitoring programs of operators in their region. The review found that a number of the operators were not complying with relevant requirements.

The introduction of AD/ENG/5 allowed life extensions to be approved for PT6A engines in Australia under less restrictive circumstances compared with those required by the engine manufacturer. By allowing a wider range of operators to extend TBOs, there was an onus on CASA to take measures to assure itself, during its surveillance activities, that operators were complying with the AD and conducting ECTM appropriately. However, CASA's surveillance system was not sufficiently rigorous to ensure that the mitigators it had introduced within AD/ENG/5 for allowing TBO extensions were effective.

The investigation also noted that the CASA system for approving maintenance organisations and maintenance controllers did not appropriately consider the maintenance organisation's resource requirements.

Flight operations issues

The investigation determined that the pilot was appropriately licensed to conduct the flight, and that it was unlikely that any medical or physiological factor's adversely affected the pilot's performance. There was also no evidence that incorrect aircraft loading or meteorological conditions were factors in the accident.

Several factors would have contributed to the aircraft's speed not being sufficient for the pilot to maintain control of the aircraft during the accident flight. These factors included the significant loss of power from the left engine just prior to, or at about the time, the aircraft became airborne, and the substantial aerodynamic drag resulting from the landing gear remaining extended and the left propeller not being feathered. In addition, the aircraft's speed when it became airborne was probably close to V_{mca} and not sufficient to allow the aircraft to accelerate to the best one-engine inoperative rate-of-climb speed (V_{yse}) of 107 kts with an engine failure.

With an engine failure or malfunction near V_{mca}, the safest course of action would be to reject the takeoff due to the likelihood of the aircraft not being able to accelerate to V_{yse}. Although in some cases this will mean that the aircraft will overrun the runway and perhaps sustain substantial damage, the consequences associated with such an accident will generally be less serious than a loss of control after becoming airborne.

In this case, the engine failure occurred during a critical phase of flight, in a situation that was among the most difficult for a pilot to respond to in a manner that would ensure a safe outcome. In addition to the timing of the engine failure, a number of factors could have influenced the pilot's decision to continue with the takeoff, including the nature of the operator's procedures, the length of the runway, and the visual appearance of the runway and buildings beyond the runway at the time of the engine failure.

The operator specified a rotation speed of 90 kts, which was less than the 96 kts rotation speed specified by the aircraft manufacturer for King Air C90 aircraft. The operator's specified rotation speed had the effect of degrading the one-engine inoperative performance capability of the aircraft during takeoff. In addition, the operator's procedures did not provide appropriate guidance for pilots regarding decision speeds or decision points to use for an engine failure during takeoff.

While aircraft manufacturers have provided guidance material in operating manuals regarding engine failures leading to power loss in multi-engine aircraft, CASA had not published formal guidance material. The level of training available for emergencies in this category of aircraft during critical phases of flight and at high aircraft weights was less than desirable.

Toowoomba aerodrome was licensed and met the relevant CASA standards. However, runway 29 did not meet the ICAO standard in relation to the runway end safety area (RESA).

Safety action

Since the accident, CASA has made changes to the requirements of AD/ENG/5 and the processes for assessing the suitability of maintenance controllers.

As a result of this investigation, the ATSB issued six recommendations to CASA relating to the following areas:

- reviewing operator compliance with the requirements of mandatory turbine engine condition monitoring programs.
- surveillance processes for confirming operator compliance with mandatory engine condition monitoring programs.
- processes for identifying priority areas for consideration during airworthiness surveillance and approval activities.
- processes to assess whether a maintenance organisation has adequate resources to conduct its required activities.
- the provision of formal advisory material to operators and pilots about managing engine failures and other emergencies during takeoff.
- the assessment of synthetic training devices for the purpose of training pilots in making decisions regarding emergencies during critical stages of flight.

As a result of this accident, the ATSB has issued a recommendation to the aerodrome operator for it to liaise with CASA to evaluate an engineering solution to enhance aircraft deceleration in the runway end safety area of runway 11/29 at Toowoomba aerodrome.

A number of issues identified during the investigation related to the aircraft operator, and would normally have resulted in safety recommendations to that organisation. However, subsequent to the accident the operator ceased operations.

1 FACTUAL INFORMATION

1.1 History of the flight

At about 0836 Eastern Standard Time on 27 November 2001, a Beech Aircraft Corporation[1] King Air C90 aircraft, registered VH-LQH, operated by Eastland Air, took off from runway 29 at Toowoomba aerodrome, Queensland for an Instrument Flight Rules charter flight to Goondiwindi, Queensland.

A witness[2] located at the aerodrome reported that he heard three noises that sounded like 'whomp', but they did not sound like explosions. When he looked up, the aircraft was approximately 600 m down the runway and it subsequently lifted off about 700 m down the runway. A second witness[3] also located at the aerodrome heard one 'banging' noise as the aircraft lifted off 700 m down the runway. These witnesses were about 250 m from the aircraft. Another witness reported that he heard three 'puff' noises, but he was not in a position to see the aircraft lift off. Other witnesses who saw the aircraft soon after it lifted off described it as being lower than normal when it passed the windsock (about 900 m along the runway). Witnesses reported that the operator's C90 aircraft typically became airborne about 600-650 m along the runway.

Witnesses reported that, as the aircraft became airborne, it developed a pronounced left yaw followed by a left bank. The aircraft then resumed a wings level attitude, and appeared to slowly gain altitude while drifting to the left of the runway centreline, before again gently banking to the left. As the flight progressed, the aircraft's attitude became gradually more nose high and left wing low. The aircraft then steadily lost altitude before the left bank angle increased abruptly and it struck power lines about 10 m above the ground and about 560 m beyond the end of the runway.

Witnesses reported that the aircraft was rolling through about 90 degrees left as it struck the powerlines. It then continued to roll left and impacted the ground inverted in a steep nose-low attitude. An intense fuel-fed fire erupted upon initial impact with the ground. The aircraft then slid across a paved roadway and the adjacent nature strip before coming to rest against a chain-link fence.

The pilot and three passengers were fatally injured and the aircraft was destroyed by impact forces and post-impact fire. The aircraft wreckage is shown in Figure 1.

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1 Beech Aircraft Corporation is now known as the Raytheon Aircraft Company.

2 See Figure 2, witness A.

3 See Figure 2, witness B.

FIGURE 1:
Aircraft wreckage

The time interval from the commencement of the take-off roll until impact was less than one minute, and the aircraft was estimated to have been airborne for about 20 seconds. Witnesses reported that the maximum height that the aircraft attained during the flight was about 100-150 ft above ground level. Witnesses also reported that the landing gear appeared to remain in the extended position throughout the flight.

Workers in an industrial shed slightly left of the runway 29 centreline, between the end of the runway and the accident site, reported hearing a noise similar to 'gravel being thrown on the roof' as the aircraft passed over the shed. Two small pieces of metallic material were recovered from the roof of this shed. Examination of these pieces indicated that they probably came from a failed engine.

The location of the accident site is shown in Figure 2.

FIGURE 2:
Aerial view showing the accident location and the runway

1.2 Injuries to persons

Injuries	*Crew*	*Passengers*	*Others*	*Total*
Fatal	1	3	-	4
Serious	-	-	-	-
Minor	-	-	-	-
None	-	-	-	-

1.3 Damage to aircraft

The aircraft was destroyed by impact forces and post-impact fire.

1.4 Other damage

The aircraft disrupted a number of electrical powerlines and a support pole. The road surface was damaged by the post-impact fire and a chain-link fence was damaged by the tail of the aircraft as it came to rest.

1.5 Personnel information

Personal details	Male, age 28 years
Type of licence	Air Transport Pilot (Aeroplane) Licence
Instrument rating	Command Multi-Engine
Medical certificate	Class 1, no restrictions
Flying experience (total hours)	3,840.0
Hours on the type	479.8
Hours flown in the last 24 hours	7.2
Hours flown in the last 7 days	13.4
Hours flown in the last 90 days	120.6
Last check flight	7 May 2001
Last check flight on type	20 February 2001

The pilot was qualified to conduct the flight. He held an Air Transport Pilot (Aeroplane) Licence issued on 1 November 2001. He was issued a Commercial Pilot Licence and a Command Multi-Engine Instrument Rating (CMEIR) in 1994. The pilot's flying logbooks showed that he was regularly employed as a pilot over the following years and averaged about 500 flying hours per year. Approximately 70 per cent of his flying hours were on multi-engine aircraft and his CMEIR was renewed annually.

The pilot was employed as a line pilot with the operator in August 2000, initially based in Roma, Queensland. The C90 aircraft was his first turbine-engine endorsement. After completing the endorsement training in September 2000, he undertook 51 hours (45 sectors) of line training.[4] At the completion of that training the pilot underwent a base check on 26 October 2000. He failed that check flight for what was reported to have been inadequate knowledge of civil aviation regulations and the operator's policies and procedures, including emergency procedures. The flying sequences were graded as a pass. The pilot passed the subsequent re-test on 2 November 2000.

The pilot underwent instrument rating, base and route checks on 20 February 2001, all of which were recorded as being carried out to a satisfactory standard. The last check flight undertaken by the pilot before the accident was on 7 May 2001. That was undertaken in the US in a Piper PA-44 Seminole aircraft, for the issue of a US Air Transport Pilot licence. The check involved 4.3 hours of flying, including 3.6 hours instrument flight.

The pilot had been operating from Toowoomba aerodrome for almost 5 months prior to the accident. Examination of his logbook and the operator's records indicated that, between 1 July and 26 November 2001, the pilot had conducted 52 takeoffs from that aerodrome. The pilot had conducted most of his recent flying in LQH.

The pilot was reported to have been well rested and in good health prior to the flight. A review of his flight history showed that he had worked a total of 9.3 hours on the day prior to the accident. This included 7.8 hours flight time[5] and involved seven takeoffs and landings. He had the previous three days free of duty. Witnesses reported that, on the day of the accident, the pilot's pre-flight activities appeared normal and unhurried.

4 The operator's *Operations Manual*, Part C, stated that a crew member was required to complete 50 hours acting as pilot-in-command under supervision before being cleared for line operations.

5 The pilot recorded his flight time from engine start to engine shutdown.

1.6 Aircraft information

1.6.1 Aircraft description

Manufacturer	Beech Aircraft Corporation, US
Model	King Air C90
Serial number	LJ-644
Powerplants	Two Pratt & Whitney Canada PT6A-20A
Registration	VH-LQH
Year of manufacture	1975
Category of operation	Charter
Certificate of airworthiness	BN/10847 dated 18 April 1998
Certificate of registration	BN/10847/01 dated 15 April 1998
Maintenance release	Issued 7 June 2001, valid until 6,992.2 hours[6] or 7 June 2002
Total time in service (TTIS)	6,968.7 hours

A review of the aircraft maintenance documentation indicated that the aircraft had been imported from the US and placed on the Australian civil register on 18 April 1998. At that time, the aircraft had a total time in service (TTIS) of 5,580.6 hours. The US documentation indicated that the aircraft had been operated in a charter/private role since initial entry into service. There was no evidence of any previous major airframe, engine or propeller damage. The maintenance organisation that placed the aircraft on the Australian civil register on behalf of the operator certified that the aircraft complied with all of the relevant Australian airworthiness directives, inspections and modifications.

A review of the aircraft's maintenance and operational documentation revealed recording errors in the logbooks and maintenance documentation. The daily operational flight log for the day prior to the accident indicated a TTIS of 6,931.2 hours. The flight logs for the aircraft between 17 April 1998 and 27 November 2001 recorded 37.5 hours more than was indicated in the engine logbooks and annotated on the current maintenance release. Accordingly, the TTIS at 27 November 2001 was recalculated to be 6,968.7 hours.[7]

1.6.2 Engine description

The PT6A-20A is a gas turbine engine incorporating two counter-rotating turbines; one driving the compressor and the other driving a propeller through a reduction gearbox. The power turbine driving the propeller is 'free' or independent of the compressor turbine. A cutaway diagram of the engine is shown in Figure 3.

During the engine starting process, the compressor draws air into the engine, compresses it, and delivers it to the combustion chamber. When the correct compressor speed is reached, fuel is introduced into the combustion chamber. In the PT6A-20 series engine, two manually operated spark igniters located in the combustion chamber ignite the mixture and the combustion gases are then directed to the turbines. The propeller starts to rotate at that point.

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6 The term 'hours' is used throughout the report to indicate aircraft hours unless otherwise specified.

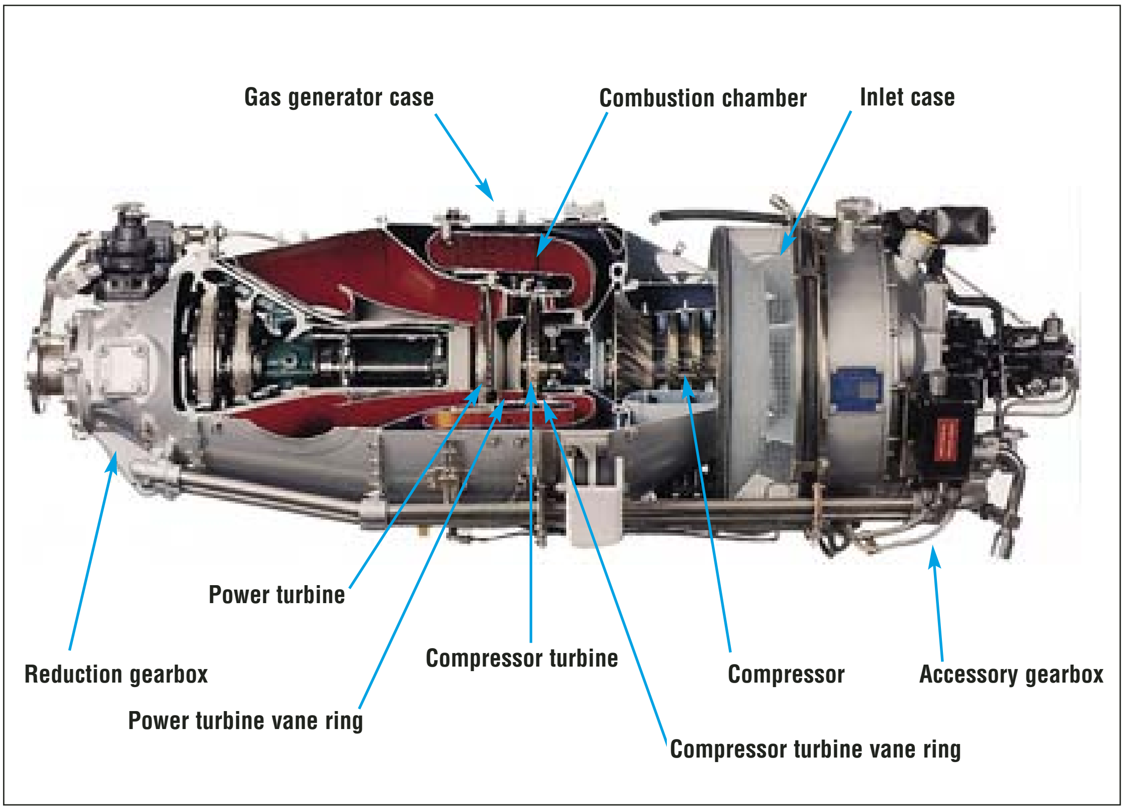
7 The investigation noted that, as a result of the recalculation of aircraft hours, a recalculated due date on the maintenance notification spreadsheet indicated that inspections outlined in two Airworthiness Directives (AD/BEECH 90/14 and AD/BEECH 90/48) had not been conducted by the required time. Neither of these inspections was related to the accident.

The gases accelerate through the compressor turbine vane ring and cause the compressor turbine to rotate. The gases then travel across the power turbine vane ring and provide rotational energy to the power turbine. The reduction gearbox reduces the power turbine's speed (approximately 30,000 RPM) to a speed suitable for propeller operation (approximately 2,000 RPM). As the engine reaches idle speed, ignition is manually turned off since a continuous flame exists in the combustion chamber.

The 'cold section' of the engine consists of the gas path components upstream of the combustion chamber, including the inlet case, compressor, bleed valve and gas generator case. The compressor consists of three stages of axial compressor and a single stage centrifugal compressor coupled to and driven by the compressor turbine.

The 'hot section' of the engine consists of the gas path components in contact with the hot gases including the combustion chamber, vane rings, a single compressor turbine and a single power turbine. The compressor turbine extracts energy from the combustion gases in order to drive the compressor.

FIGURE 3:
Cutaway diagram of a PT6A engine



1.6.3 Left engine

Engine manufacturer	Pratt & Whitney Canada
Engine type and model	Turboprop, PT6A-20A
Serial number	24105
Total time since new	6,831.0 hours[8]
Time since overhaul	3,556.0 hours
Cycles[9] since overhaul	3,858
Next engine overhaul due at	6,875.0 hours

Maintenance documentation indicated that the left engine was fitted to the aircraft at original manufacture. When the aircraft was placed on the Australian civil register, the left engine TTIS was 5,442.5 engine hours. The engine log indicated that the engine was overhauled previously at 3,275 engine hours TTIS.[10] The aircraft had completed a total of 1,388.5 hours since entering service in Australia.

The engine manufacturer's specified time between overhaul (TBO) for the engine type was 3,600 hours.[11] As part of an audit on 28 January 1999, the Civil Aviation Safety Authority (CASA) noted that the left engine satisfied the requirements of Airworthiness Directive[12] AD/ENG/5, *Turbine Engine Continuing Airworthiness Requirements*. AD/ENG/5 was issued to require turbine engines to be overhauled or inspected at specified intervals (see Section 1.17.2). It allowed the TBO for PT6A engines to be extended to 5,000 hours if a number of requirements were met, including the use of an engine condition trend monitoring (ECTM)[13] program (see Section 1.17). The operator had elected to extend the TBO of its PT6A engines to 5,000 hours under the provisions of AD/ENG/5 (see Section 1.17.2). Accordingly, both engines on LQH were subject to an ECTM program (see Sections 1.18.8, 1.18.9 and 1.18.10).

Pratt & Whitney Canada (PWC) Service Bulletin[14] (SB) 1803 recommended that the compressor turbine blades in PT6A-20A engines be inspected at 5,000 hours time since new and thereafter at intervals of 3,000 hours. At the time of the accident, the compressor turbine of the left engine had a total of 3,556 hours since overhaul. The blades were inspected at the engine's last overhaul. However, the available maintenance documentation did not indicate whether new blades were fitted at that time.

The maintenance documents showed that when the aircraft was placed on the Australian civil register, the engines were examined and found to comply with the requirements of AD/ENG/7 *Replacement of Life Limited Turbine Engine Components* and AD/ENG/5.

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8 Due to the discrepancy occurring over the period from when the aircraft was entered on the Australian civil register until the time of the accident, the engine total time since new and time since overhaul have been corrected for the 37.5 hours discrepancy (see Section 1.6.1). The same corrections were also applied to the right engine.

9 A cycle is defined as an engine start-up, takeoff, landing and shutdown.

10 The aircraft had completed 137.2 hours more total time than the left engine total time. This difference in hours would indicate that another engine was probably fitted to the aircraft for the period that the left engine underwent overhaul while in the US, and before the aircraft entered service in Australia.

11 The specified TBO was increased from 3,500 hours to 3,600 hours by Service Bulletin 1003 Revision 25, dated 4 February 1999 (see Section 1.17.2).

12 An airworthiness directive is a document issued by CASA that requires mandatory action to address an unsafe condition that exists, or is likely to exist, or could develop, in an aircraft, engine propeller or component. Airworthiness directives may incorporate the requirements of manufacturer service bulletins.

13 ECTM is the proprietary name that the engine manufacturer used to describe its recommended program for engine condition monitoring. Other turbine engine manufacturers have developed similar programs.

14 A service bulletin is a document used by a manufacturer to notify operators of recommendations that may address safety or airworthiness related problems or operational or economic matters. Service bulletins may require action for inspection, repair, rework, modification, part replacement and functional checks of an aircraft. A service bulletin may be incorporated into an airworthiness directive to make it legally binding.

The aircraft maintenance documentation showed that the last hot section inspection[15] was conducted at 5,263.9 engine hours, prior to the aircraft entering Australia. A boroscope inspection[16] of the engine hot section was conducted on 15 December 2000 at 6,428.2 engine hours.

The last recorded maintenance for the engine was completed on 7 June 2001 at 6,634.5 engine hours (6,772.2 aircraft hours). In accordance with the requirements of AD/ENG/5 Amendment 7, that maintenance consisted of an inspection of the oil filter, reduction gearbox chip detector, and first stage compressor inlet. A performance recovery wash and a power assurance engine run[17] were performed as well as an inter-turbine temperature (ITT) harness resistance check.

1.6.4 Right engine

Engine manufacturer	Pratt & Whitney Canada
Engine type and model	Turboprop, PT6A-20A
Serial number	20577
Total time since new	18,512.3 hours
Time since overhaul	365.3 hours
Cycles since overhaul	415

The right engine was overhauled prior to installation on the aircraft on 15 December 2000. The last recorded maintenance for the engine was completed on 7 June 2001 at 18,353.3 engine hours. In accordance with the requirements of AD/ENG/5 Amendment 7, that maintenance consisted of an inspection of the oil filter, reduction gearbox chip detector, and first stage compressor inlet. A performance recovery wash and a power assurance engine run were performed, and an ITT harness resistance check was conducted.

A review of the maintenance records and the operator's flight logs could find no evidence to indicate that either engine had exceeded the ITT start temperature limits (hot start) in recent months. There was also no indication that there was a pre-existing defect with any of the engine instruments. The maintenance records showed that the engine instruments were last calibrated in accordance with the AD/INST/9 *Instruments in IFR Aircraft – Test Requirements* Amendment 5 during a phase 3 radio and corrosion control inspection that took place between 2 and 7 June 2001.

1.6.5 Propeller feathering system

In the absence of engine power, the propeller of a failed engine is rotated by the airflow on the propeller blades, which are usually in a low blade angle position during takeoff and initial climb. The windmilling propeller is effectively a disc, creating a significant amount of resistance to the airflow, resulting in aerodynamic drag. This drag is minimised by 'feathering' the propeller, which increases the angle of the blades until they are streamlined, with the leading edge of the blades pointing into the direction of aircraft travel and therefore offering minimum resistance to the airflow. The majority of the propellers fitted to multi-engine aircraft have the capacity to be 'feathered' (see also Section 1.20.4.2).

15 A hot section inspection involves an internal examination of the turbine section.

16 A boroscope is a flexible optical instrument which is used to conduct an internal examination of the engine.

17 A power recovery or performance recovery wash involves the injection of a chemical solution into the compressor internal section of the engine to clean possible contaminants, such as dust and salt deposits, for the purpose of performance recovery. An engine ground run (power assurance run) is carried out to confirm that it is developing rated power.

An engine-mounted governor controls the propeller blade angle by varying the flow of oil to and from the propeller. Feathering can be manually initiated by retarding the propeller lever past the normal control range to the feather position. Some aircraft are also fitted with an automatic propeller feathering system designed to automatically feather the propeller of an inoperative engine during takeoff and landing.

LQH was fitted with an automatic propeller feathering system designed to initiate feathering when engine torque fell below 160-240 foot-pounds. The normal torque during takeoff was approximately 1,175 foot-pounds. The automatic feathering process takes approximately 7 seconds, and about 15 seconds for propeller rotation to cease. To activate the system, the auto-feather arm switch must be placed in the ARM position prior to takeoff. This switch is located on the inboard lower left instrument panel in the aircraft cockpit. The system is then armed when both power levers are moved above approximately the 90 per cent N1 (compressor and compressor turbine speed) position, as determined by micro-switches in the pedestal. If an engine subsequently fails or malfunctions, the propeller of that engine will feather when the torque drops below the value noted above. If the power lever is retarded below the 90 per cent N1 value, the auto-feather system will be disarmed. The operator's normal procedure was for the auto-feather system to be armed for takeoff.

A review of the maintenance documentation found that in July 2001 the auto-feather system on the right propeller was not arming. A micro-switch was found to be out of adjustment. Corrections were made according to the manufacturer's procedures, and there were no reported recurrences of any problems. There was no evidence of any recent propeller feathering system defects associated with the left engine.

1.6.6 Landing gear

Landing gear retraction and extension was electrically operated and controlled by a selector handle located on the inboard, lower right instrument panel. When fully extended, the landing gear was locked in the down position by a mechanical hook and an overcentre mechanism.

A review of the maintenance records did not find any recent reported unserviceabilities with the aircraft's landing gear system.

1.6.7 Weight and balance

The pilot completed the operator's aircraft manifest and load statement prior to the flight and calculated the take-off weight as 4,170 kg, including 997 kg fuel. The maximum permissible take-off weight for the aircraft was 4,377 kg. The actual seating position of the passengers in the aircraft prior to departure could not be established. The investigation estimated that the take-off weight was within 10 kg of the above figure at the time of the accident and, assuming the least favourable seating arrangements, the aircraft would have been within the weight and balance limitations specified in the aircraft's *Approved Flight Manual*.

1.6.8 Fuel

Aircraft documentation indicated that the aircraft carried sufficient fuel for the intended flight. Due to the extent of the post-impact fire, testing of the Jet A1 aviation turbine kerosene carried on board the aircraft was not possible. Laboratory analysis of a sample of the same fuel batch loaded on board the aircraft confirmed that it was of the correct grade and specification.

1.7 Meteorological information

The weather assessment provided by the Bureau of Meteorology indicated that, at the time of the accident, the wind was from 249 degrees magnetic at 5 kts, crosswind 3 kts, the temperature was 20 degrees Celsius, the barometric pressure was 1011 hectopascals, there was broken cloud at 1,500 ft above the aerodrome, and visibility was greater than 10 km. There was no evidence to indicate that prevailing weather conditions contributed to the development of the accident.

1.8 Aids to navigation

Not applicable.

1.9 Communications

Radio transmissions on the Toowoomba Mandatory Broadcasting Zone frequency were recorded. At 08:33:07, the pilot made a radio broadcast on the Toowoomba frequency indicating that the aircraft was taxiing for a departure to the west, and intended to use runway 29. At 08:35:37, the pilot reported that the aircraft was about to commence the take-off roll. No further transmissions were recorded from the aircraft. There was no evidence to indicate that there were any problems with radio communication equipment or facilities.

1.10 Aerodrome information

1.10.1 General

Toowoomba aerodrome was situated 4 km west of the Toowoomba central business district and it was 2,086 ft above mean sea level. It was operated by Toowoomba City Council. Runway 11/29 (see Figure 4) was aligned 106/286 degrees magnetic, was 1,121 m long and 30 m wide, and had a bitumen surface. A second runway, 06/24, was aligned 062/242 degrees magnetic, was 660 m long and was not sealed.

FIGURE 4:
Aerial view of runway 29

Examination of Toowoomba City Council engineering diagrams indicated that for the first 170 m of runway 29 there was an upward slope in excess of 1.25 per cent. This slope gradually reduced until the peak of the runway, which occurred at a point 780 m from the runway 29 threshold. The runway then sloped downward to the west at a gradient of about 1.5 per cent for the last 40 m. The effect of the upward slope was to increase the take-off run of an aircraft (see Section 1.20.6).

The positive to negative change in gradient over the length of the runway created a visual limitation for pilots, such that one end of the runway could not be seen from the other.[18] During the take-off roll on runway 29, industrial buildings started to become visible, from the pilot's position in a C90 aircraft, when the aircraft was about 450 m from the end of the runway.[19] The end of runway 29 did not become visible until the aircraft was about 350 m from the end of the runway. The operator reported that the sudden appearance of the end of the runway late in the take-off roll could predispose pilots to believe that it was closer than it actually was. Views from the cockpit of a King Air aircraft at various points along runway 29 are shown in Figure 5.[20]

To assist in overcoming the visual limitation associated with the runway gradient, the aerodrome operator had installed distance-to-go markers at positions 600 m, 400 m and 200 m from the respective ends of runway 11/29. The runway dimensions and runway slope are shown in Figure 6.

In the period 1981 to 2000, there were seven accidents involving aircraft either travelling to or from Toowoomba aerodrome and occurring outside the aerodrome boundary, but within 20 km of the aerodrome. Of these accidents, none were related to the length of the runway or other aspects of the runway.

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18 At the time of the accident, the *En-route Supplement Australia* section on Toowoomba aerodrome stated 'ACFT [aircraft] at opposite ends of RWY [runway] 11/29 may be out of sight from each other'. The supplement is published by Airservices Australia and provides pilots with aerodrome information.

19 Since the establishment of the aerodrome, urban development had expanded to the extent that Toowoomba aerodrome was surrounded on all sides by residential or industrial buildings.

20 The photographs were taken from a Super King Air B200 aircraft. The shape and size of the cockpit area, and the seat height above the runway, was the same as the King Air C90.

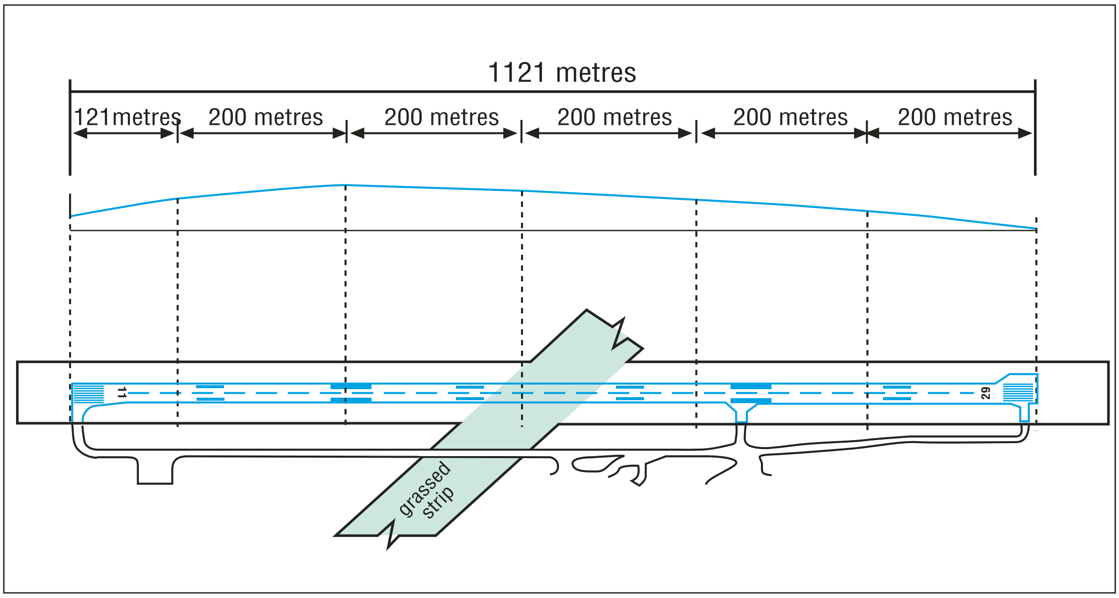
FIGURE 5:
Views from a King Air cockpit on runway 29

View from runway 29 threshold

View just prior to the 400 m distance to-go-marker

View just prior to the 200 m distance to-go-marker

FIGURE 6:
Toowoomba aerodrome runway 11/29 dimensions and slope



1.10.2 Runway design standards and recommended practices

Toowoomba aerodrome was licensed in accordance with the mandatory standards prescribed in the CASA publication, *Rules and Procedures for Aerodromes* (RPA). Runways were classified according to a reference code, which indicated their suitability for use by specific categories of aeroplanes. Runway 29 at Toowoomba was classed as a code 2 runway.[21]

One of the standards in the RPA was the requirement for a runway strip at the end of each runway. For a code 2 runway, the required length of the runway strip was 60 m. The RPA also required a runway end safety area (RESA), which was an area, intended to reduce the risk of damage to an aeroplane if it touched down before the threshold, or overran the end of a runway during a landing or a rejected takeoff. The section on RESAs in the RPA included the following information:

> 7.18.2 – The whole or part of a RESA may be included in the runway strip. In Australia, a RESA originates from the end of a runway, or stopway, if provided. It should be noted that this is different from international practice which defines the origin of RESA as from the end of a runway strip.
>
> 7.18.3 – A RESA should be provided at each end of a runway, or stopway if provided, for as great a distance as is practicable.
>
> 7.18.4 – The minimum length of the RESA is to be 90 m where the associated runway is suitable for aircraft with a code number of 3 or 4 and is used by regular public transport jet aeroplanes. In other cases, the minimum RESA length is automatically provided for by the requirement for the runway strip to extend beyond the end of a runway.
>
> 7.18.9 – The longitudinal slope of a RESA is not to exceed a downward slope of 5%. Slope changes are to be as gradual as practicable and abrupt changes or sudden reversal of slopes are to be avoided.

Toowoomba did not have a stopway at the end of the runway 29. It had 60 m of runway strip at the end, which satisfied the requirement for a RESA. The runway strip had a downward slope of

21 The runway code number referred to the aeroplane reference field length, which was the minimum field length required for takeoff at maximum take-off mass at sea level, in standard atmospheric conditions, in still air and with zero runway slope.

about 1.5 per cent. There was about an extra 40 m of open ground between the end of the runway strip/RESA and an adjacent roadway (see Figure 7). The additional 40 m sloped down at about 9 per cent.).

FIGURE 7:
Aerial view of the runway 29 RESA

The International Civil Aviation Organization (ICAO) standard for a runway strip for a code 2 runway was 60 m.[22] The ICAO standard for a RESA for a code 2 runway was 90 m. The ICAO standard also stated that the RESA shall extend from the end of the runway strip, not the actual runway. For Toowoomba aerodrome to have complied with ICAO standards, runway 29 needed a minimum of 150 m of clear area beyond the end of the runway. At the time of the accident there was about 100 m of clear area. ICAO also recommended that the RESA be 120 m, the longitudinal slope of the RESA should not exceed a downward slope of 5 per cent, and abrupt changes in slope should be avoided.

Section 11 of the Australian *Civil Aviation Act 1988* stated that:

> CASA shall perform its functions in a manner consistent with the obligations of Australia under the Chicago Convention and any other agreement between Australia and any other country or countries relating to the safety of air navigation.

Australia, as a party to the Chicago Convention, undertakes to make all efforts to comply with ICAO standards, and undertakes to notify ICAO of any differences from the standards. At the time of the accident, Australia had not filed a difference with ICAO with respect to Annex 14.

---

22 Annex 14 to the Convention on International Civil Aviation, *Aerodromes*, Volume 1: *Aerodrome Design and Operations* (Third edition, July 1999).

1.11 Flight recorders

The aircraft was not fitted with a flight data recorder or cockpit voice recorder, nor was it required to be by relevant aviation regulations.

1.12 Wreckage and impact information

The initial impact occurred when the aircraft struck powerlines about 10 m above ground level and about 560 m beyond the end of the runway. Ground impact marks showed that the aircraft was in an inverted attitude and rapidly rolling to the left when it struck the ground in a steep nose-low attitude. The right wing tip struck the ground first, followed by the right engine and the nose section of the aircraft. Fire enveloped the aircraft during the impact sequence.

The right wing broke in two places during the impact sequence and came to rest partly beneath the cabin area of the wreckage. Fuel from the ruptured right wing tank contributed to the intensity of the post-impact fire.

All major parts of the aircraft structure were identified in the wreckage. Examination confirmed that the landing gear was locked in the extended position at impact. The wing flaps were fully retracted, which was consistent with the normal take-off setting. The elevator and rudder trim settings were within the range of normal take-off settings. All damage observed to the aircraft flight control systems was consistent with impact forces and post-impact fire.

The propeller ground impact marks for the right engine indicated that the propeller was rotating at impact and that the engine was developing significant power. The propeller ground marks for the left engine indicated that the propeller was rotating at impact, but there was no indication that the engine was developing significant power. Both the left and right engines and propellers were severely damaged by impact forces and the post-impact fire. Further information about the nature of the damage to the two engines is presented in Section 1.16.

The nature of the impact and subsequent fire damage prevented any useful information being obtained from the engine instrument indications, or the selected position of the engine controls in the cockpit, including the propeller auto-feather system components. The investigation was unable to determine whether the auto-feather system was armed at the time of the accident. The investigation was also unable to determine if the left power lever was retarded during the accident flight, or whether manual feathering of the left propeller had been attempted. The King Air C90 instrument panels and the damaged left instrument panel of LQH are shown in Figure 8.

There was no evidence of bird debris on the runway, and no evidence of a birdstrike or other foreign object damage was found during the examination of the engines. There were no reports of bird activity at the aerodrome at the time of the accident.

The location of the accident site in relation to the runway is shown in Figure 9.

FIGURE 8A:
King Air C90 instrument panel

FIGURE 8B:
Indicates the extent of impact and fire damage to cockpit instruments

FIGURE 9:
Aerial view showing the accident location

1.13 Medical and pathological information

Post-mortem examination of the pilot revealed that he died as a result of impact forces. The examination also revealed that the pilot had scattered areas of atheroma in the coronary arteries, consistent with generalised moderate coronary heart disease. However, medical advice indicated that the severity of the coronary artery disease can be over-estimated if a body is exposed to thermal damage.

The post-mortem examination found no evidence of histological changes consistent with an acute or previous heart attack. Medical advice indicated that, if such an event had occurred during the accident flight, it would probably not have been detected pathologically. Interviews with the pilot's family and medical personnel, and a review of his medical records, found no prior indication of cardiovascular problems.

There was no evidence that medication, alcohol, carbon monoxide or other toxic substances adversely affected the pilot at the time of the accident. There was no other evidence to indicate that the pilot may have become incapacitated prior to impact.

1.14 Fire

The aircraft wreckage was consumed by an intense post-impact fire. There was no evidence found of an in-flight fire.

1.15 Survival aspects

The accident was not considered to be survivable, due to impact forces and post-impact fire.

1.16 Engine and propeller examination

After recovery from the accident site, the engines were disassembled by a representative of the engine manufacturer under ATSB supervision at the engine manufacturer's local overhaul facility. The initial examination of the left engine found that the gas generator displayed contact signatures indicating the loss of 'useful' or thrust-producing power. The loss of useful power appeared to be due to the fracture of one or more compressor turbine blades, and their subsequent impact with adjacent and downstream components. The left engine displayed contact signatures indicating that the power turbine was rotating with considerable energy at impact. The initial examination concluded that the overall pattern of evidence was characteristic of the propeller being unfeathered and rotating under air loads at the time of impact. The initial examination of the right engine found that the damage within the engine was consistent with it developing considerable power at the time of impact. Other findings of the initial examination of the engines are outlined in Appendix A.

The engine manufacturer subsequently conducted a more detailed examination of the left engine in Canada under the supervision of the Transportation Safety Board of Canada (TSB).[23] This examination did not provide any additional conclusions regarding the nature of the damage to the engine. The manufacturer reported that the separation of the compressor turbine blades and their subsequent impact with adjacent blades would create a gross disruption of gas flow and compressor efficiency, resulting in a severe power loss. The report considered that 'it was unlikely that the gas generator could have been producing sufficient gas flow to provide thrust at the time of impact'.

The propeller manufacturer conducted an examination of both propellers under the supervision of the TSB. It noted that blade butt impressions and other witness marks were consistent with the left propeller not being feathered at impact. There was no meaningful information concerning blade bending or twisting of the left propeller. The blade twisting of the right propeller suggested that it was rotating at the time of impact. The manufacturer concluded that there was no evidence that either propeller was feathered at the time of impact.

Figure 10 shows an undamaged PT6A-20 compressor turbine wheel of the same model as those installed in the engines of LQH. Figure 11 shows the left engine compressor turbine blade damage. Figure 12 shows a close-up view of the damage to the blades.

[23] The TSB is the Canadian equivalent of the ATSB.

FIGURE 10:
Undamaged PT6A-20 compressor turbine assembly

FIGURE 11:
LQH left engine compressor turbine assembly

FIGURE 12:
LQH left engine compressor turbine

The TSB subsequently conducted a metallurgical failure analysis of the engines and propellers on behalf of the ATSB. The TSB report referred to examination reports conducted by the engine manufacturer and the propeller manufacturer. The complete text from the TSB report on the engines and propellers is at Appendix B.

The key findings of the TSB examination of the left engine and propeller were:

- The blade aerofoils of the compressor turbine were fractured at varying heights from the root to approximately one half-span. The fractures displayed general features of overload failure.
- The damage pattern observed in the left engine was consistent with the release of a blade from the compressor turbine, which resulted in the damage to other blades. The resulting blade debris led to extensive damage of other components of the engine. The blade which initially failed could not be identified due to extensive mechanical damage to the blade remnants.
- The compressor turbine blade material satisfied specification requirements. Examination of the remnants of the compressor turbine by the TSB indicated that no manufacturing or processing defects were present. There were no indications of fatigue or material creep. [24]
- The microstructure of a representative compressor turbine blade indicated that the blade had been exposed to above normal operating temperatures.[25]
- The evidence from the pitch position of the left propeller blades at impact indicated that the propeller was not feathered.

The key findings of the TSB examination of the right engine and propeller were:

- There was substantial rotational damage and circumferential damage to the engine components (see Figure 13), which led to the conclusion that the engine was developing significant power at impact.
- There were no indications of any pre-impact operational distress to any of the right engine components.
- The evidence from the pitch position of the right propeller blades at impact indicated that the propeller was not feathered.

24 American Society for Metals, 1986, *Metals Handbook Ninth edition, Volume 11, Failure Analysis and Prevention*, stated:

> **fatigue.** The phenomenon leading to fracture under repeated or fluctuating stresses having a maximum value less than the ultimate tensile strength of the material.
>
> **creep.** Time-dependent strain occurring under stress.

25 The TSB report did not comment on the reasons for the above normal operating temperatures.

FIGURE 13:
LQH right engine compressor turbine as located within the engine

1.17 Engine condition and trend monitoring (ECTM)

The operator was using engine condition trend monitoring (ECTM) on all turbine engines fitted to its aircraft, including both engines of LQH. This section outlines the general nature of ECTM, the reasons for using ECTM, and the regulatory requirements and manufacturer's guidelines for using ECTM. The ECTM data for the engines on LQH is presented in Section 1.18.9.

1.17.1 Overview[26]

During normal operation, gas turbine engines such as the PT6A-20A are capable of producing rated power for extended periods of time in service. However, the efficiency of the engine can reduce over time due to a variety of factors. For example, engine gas path components such as compressor vanes and blades and turbine vanes and blades are exposed to factors such as dirt or chemical particles in the air that can damage, erode or contaminate the airfoil shaped surfaces of those components. The efficiency of those components in performing their intended gas compression or expansion functions can become degraded as a result. Engine hot section components can be exposed to excessive temperatures through inadvertent or irregular handling or faulty maintenance equipment. This can also result in degraded performance.

Under specific flight conditions, engine operating parameters will be predictable if the engine is producing its rated power. ECTM is a process that predicts the values of these parameters, compares those predictions with data recorded during flight, and analyses the differences.

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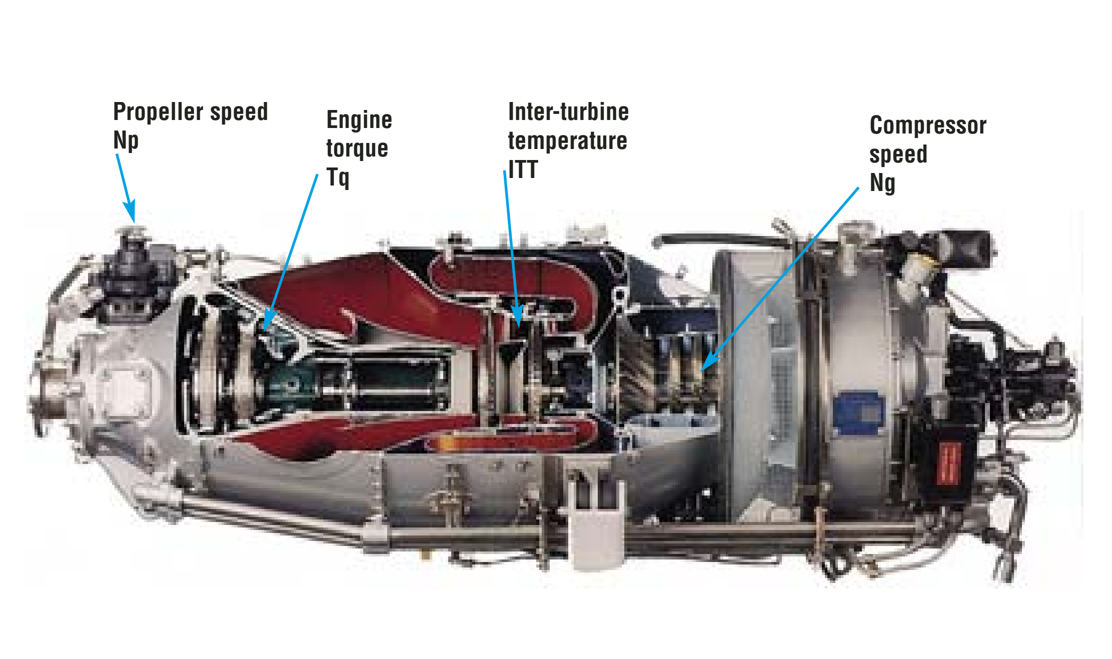
26 The majority of the information in this section was obtained from the engine manufacturer's publication *ECTM Training Manual*, 5th edition, July 2000.

The following three engine gas path parameters are recorded during the ECTM programs for PT6A-20A engines:

- Compressor speed (Ng), or the rate of rotation of the compressor section of the engine.
- Inter-turbine temperature (ITT), or the gas temperature measured between the compressor turbine and power turbine stages of the engine.
- Fuel flow (Wf), or the mass fuel flow rate to the engine.

Figure 14 presents a diagram of a PT6A engine, which shows where the engine parameters are measured.

Figure 14:
Location of the PT6A engine gas parameters



In addition, outside air temperature, indicated airspeed, pressure altitude, engine torque (Tq), and propeller speed (Np) are required to be recorded. The manufacturer's computer software model calculates the predicted values of the three gas path parameters using these other five parameters. The differences between the recorded values and the predicted values of Ng, ITT and Wf are termed 'deltas'.

The ECTM computer software displays the delta for each engine gas path parameter in relation to a baseline (for example see Section 1.18.9 and Figure 15). The baselines are calculated by the software using the first 15 recorded deltas after the engine is introduced into service, or after a significant maintenance activity, such as an overhaul or hot section inspection. As raw values will vary from recording to recording, the software also displays trend lines. Analysis of the trend lines over time reveals the magnitude and rate of any deviation from the baseline.

The manufacturer's recommended option for displaying trend lines is a 'general smoothing' function. This function considers the data points both before and after the data point for a date of interest when calculating a trend line value for that date. That is, the trend line value for a particular date may change when additional data points are included after that date.

The recording of the required parameters can be done either automatically (if the aircraft is equipped with appropriate equipment) or manually by the pilot during flight. Manual recording involves a pilot taking readings from relevant instruments in the cockpit.

1.17.2 Reasons for using ECTM

By using ECTM, an aircraft operator could track an engine's performance over time and detect early signs of deterioration. Based on the pattern of changes across the three gas path parameters, the operator could also make a preliminary diagnosis of the nature of a problem and the required maintenance actions, such as performance recovery washes and engine instrument maintenance. According to the engine manufacturer, ECTM was introduced to improve safety, reduce costs and save time. The engine manufacturer encouraged operators to use ECTM because of these advantages.

Another advantage of using ECTM was that it could provide a basis for extending the required TBO or allow hot section inspections to be conducted less frequently. In May 1985, CASA introduced Airworthiness Directive AD/ENG/5 *Turbine Engine Continuing Airworthiness Requirements*. Amendment 7[27] became effective on 14 June 2001. Paragraph 2.4 of AD/ENG/5 Amendment 7 stated that:

> (a) PT6A-20 series engines shall be overhauled at periods as listed in, and subject to the requirements of, the appropriate Pratt and Whitney Canada Service Bulletin detailing Pratt and Whitney Canada PT6A-20 operating time between overhaul and hot section inspection frequency; or
>
> (b) At periods not to exceed 5,000 hours time in service, subject to compliance with the maintenance requirements detailed in Appendix A of this Directive; or
>
> (c) As detailed in an approved system of maintenance.

The operator of LQH elected to use option (b), which required compliance with the requirements of Appendix A of the AD, including the requirement for ECTM to be conducted. Therefore, by electing to use option (b), the operator was required to use ECTM as a basis for extending the TBO for the engines on its fleet of aircraft.

As outlined in paragraph 2.4 (c) of AD/ENG/5, operators could also extend TBO intervals if they had an 'approved system of maintenance'. One method of meeting this requirement, which also existed prior to the introduction of AD/ENG/5, was to obtain extensions through the engine manufacturer. The manufacturer specified TBOs and hot section inspection intervals for its engines in service bulletins (SBs).

PWC SB1003, revision 23 (SB1003R23), dated 6 April 1998, was applicable when LQH was placed on the Australian civil register. It specified a TBO of 3,500 hours for a range of the manufacturer's engines (including the PT6A-20). The SB also stated that the TBO for an operator's fleet could be increased in increments not exceeding 500 hours '…on a sampling basis, and following one satisfactory exhibit at each level'.[28] A satisfactory exhibit meant that one engine at or near the specified TBO needed to be inspected and overhauled. In addition, the overhaul facility had to provide an evaluation report on the engine to the manufacturer, and the manufacturer would consider this report before recommending a fleet extension. The SB stated that any extensions were subject to the approval of the operator's local regulatory authority.

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27 Amendment 7 of AD/ENG/5 was essentially the same as amendment 6 (11 September 1997), except that it added a requirement specific to PWC PT6A-20 engines operated in aerial agricultural operations.

28 That is, for each increment of 500 hours to the TBO, a different sample engine had to be overhauled and evaluated before a further extension of 500 hours would be provided for the rest of the fleet's engines.

The SB did not specifically require ECTM to be conducted in order to obtain a TBO extension, because its approval process relied on a physical hardware examination of a sample engine at overhaul. However, SB1003R23 also stated that PT6A engines could be operated to a scheduled hot section inspection interval (1,750 hours for PT6A-20A engines), or the frequency of the inspections could be based on ECTM. If ECTM was introduced part way through an engine's life, a compressor wash and hot section inspection were required to establish an appropriate baseline.

SB1003R23 was superseded by several revisions as follows:

- SB1003R24, dated 24 November 1998, did not change TBO or hot section inspection interval requirements.
- SB1003R25 dated 4 February 1999, changed the specified TBO from 3,500 hours to 3,600 hours, and the specified hot section inspection interval from 1,750 hours to 1,800 hours.
- SB1003R26, dated 3 October 2000, provided more detailed guidance from the engine manufacturer on what it considered necessary for obtaining fleet extensions. For example, the manufacturer recommended that the sample engine should be operated by the same operator for the majority of the TBO interval, and that the sample engine was to be evaluated at a manufacturer-approved overhaul facility.
- SB1003R27, dated 2 May 2001, did not change TBO or hot section inspection interval requirements.

On 13 November 2001, SB1803R1 superseded SB1003R27 for PT6A-20A engines and some similar engine types. SB1803R1 stated that operators could obtain manufacturer recommendations for TBO extensions using two options, both of which recommended that the operator's engines should have an average utilisation of more than 300 hours per year. Option A was similar to that described in SB1003R27. Under option B, operators were able to obtain a life extension from the manufacturer for a specific engine provided that the operator and the engine met minimum eligibility criteria, the engines were individually registered in the manufacturer's program, and maintenance was conducted according to specific procedures outlined in the SB. The required maintenance activities included the use of ECTM to monitor engine performance.

1.17.3 Appendix A to CASA Airworthiness Directive AD/ENG/5

Appendix A to AD/ENG/5 Amendment 7 included the following statements:

> To permit a Pratt & Whitney Canada (PWC) PT6A engine to continue in service to 5,000 hours TBO, the continuing airworthiness of the engine must be assessed at specific intervals. The assessment of engine condition shall be carried out in accordance with approved maintenance data and a Civil Aviation Regulation (CAR) 42C system of maintenance.
>
> The system of maintenance shall include, but shall not be limited to, the following requirements…
>
> 2. Engine condition trend monitoring shall be carried out in accordance with the procedures detailed in the Pratt and Whitney Canada ECTM Analytical Guide (EAG)[29] manual and Airworthiness Advisory Circular (AAC) 6-29 Amdt. 1; and
>
> 3. Hot section inspections shall be carried out at intervals not to exceed:
>
>   (a) 1250 hours time in service; or

[29] The *Engine Analytical Guide* (EAG), the *ECTM Training Manual* and the *ECTM User's Guide & Reference Manual* mean the same document.

(b) 1760 hours time in service subject to a boroscope inspection of the engine hot section for evidence of cracks, distortion, burning and coating loss at intervals not to exceed 610 hours time in service; and…

9. A compressor power recovery wash shall be carried out in response to trend monitoring parameter deviations, or at intervals not to exceed 220 hours time in service, or 3 calendar months, whichever occurs first…

1.17.4 CASA Airworthiness Advisory Circular 6-29

Airworthiness Advisory Circular (AAC) 6-29 Amendment 1, issued in May 1998, contained additional CASA requirements regarding ECTM, including:

1. The trend monitoring program shall commence with the engine in a new or newly overhauled condition or alternatively, following a HSI [hot section inspection] and a compressor wash.
2. Compliance with the principles and procedures detailed in Pratt and Whitney Canada ECTM Analytical Guide (EAG) manual.
3. Documentation necessary for the recording of required data.
4. Current or acceptable revision status of applicable PWC Engine Condition Monitoring Program and applicable Instruction Manual.
5. Necessary equipment (computer, printer, calculator etc) to run the PWC ECTM program.
6. ECTM training procedures for all persons involved in the recording, entry and appraisal of ECTM.
7. A Procedures Manual (and Operating Manual if applicable) detailing practices and procedures required to be observed by all persons involved in the recording, entry and appraisal of ECTM.
8. In-flight parameters are recorded on each flying day, or every 5 flight hours.
9. At least twice weekly, those parameters are plotted and assessed by an appropriate person.
10. Appropriate procedures to respond to deviations from delta as detailed in the PWC EAG manual.
11. A system of recording and retention of all data and responses to ECTM.

The AAC was initially issued in December 1991. The introduction of the document noted that some operators had elected to delete a fixed time interval for hot section inspections and had elected to base hot section inspections on ECTM, an option outlined in the manufacturer's service bulletins. The AAC was introduced to ensure that operators who had elected to use this option were conducting ECTM in accordance with specific requirements. The operator of LQH was scheduling hot section inspections for its C90 aircraft in accordance with the intervals specified in paragraph 3, Appendix A of AD/ENG/5 Amendment 7.

1.17.5 Engine manufacturer's *ECTM User's Guide & Reference Manual*

The engine manufacturer provided a detailed description of its ECTM system in the company publication *ECTM User's Guide* & *Reference Manual* (7^{th} edition, September, 2001).[30] The manual included guidelines for the recording and interpretation of ECTM data. The manual was relevant for a range of different PWC engine models, including PT6A engines.

30 The 7^{th} edition of the manual was current at the time of the accident. The 6^{th} edition (February 2001) was essentially the same document. Some earlier versions of the manual were titled *ECTM Training Manual*. The manual was also referred to in some of the engine manufacturer's publications as the *Engine Condition Trend Monitoring Analytical Guide Manual*. The CASA AD/ENG/5 (see Section 1.17.3) included reference to a Pratt & Whitney Canada document titled the *Engine Analytical Guide* (EAG).

The manual stated that ECTM could be used if the engine was within 100 hours since new, within 100 hours since being overhauled, or within 100 hours of having had a hot section inspection and a compressor wash.

In terms of the recording of the data, the manual stated:[31]

> Ambient parameters and engine performance data should be recorded once every day, or once every six (6) flight hours if the engine is flown more than 6 to 8 hours a day, and should be processed the following day. For aircraft with an on-board automatic recorder, the cruise information should be downloaded and processed every three (3) days.
>
> **<u>NOTE:</u> Any specific ECTM instructions provided in the applicable engine Maintenance Manual or Service Bulletin will have precedence on the above.**
>
> Under exceptional circumstances, like automatic recorder malfunction, a maximum of three (3) days or 24 (running) hours of missing data is acceptable. The cause of the problem should be investigated promptly and for automatic recorder, the data should be recorded manually in the meantime…
>
> A flight with an appropriate cruise leg should be selected, preferably at a representative flight altitude (±5,000 feet from a typical altitude) and airspeed. With the engine power established and stabilized, in cruise mode, for a minimum of five (5) minutes, the following data should be recorded:
>
> Indicated Outside Air Temperature (IOAT)…
>
> Pressure Altitude (P.ALT) (altimeter reset to 29.92"Hg)…
>
> Indicated Airspeed (IAS)…
>
> Torque (TQ)…
>
> Propeller Speed (NP)…
>
> Compressor Speed (NG)…
>
> Interturbine Temperature (ITT)…
>
> Fuel Flow (WF)…
>
> Variable loads extracted from the engine, such as generator, hydraulic, air conditioning and bleeds air, will have an effect on trend accuracy. To minimize these effects, each time a set of readings is taken, it is preferable that conditions be repeated as closely as possible with regard to altitude and power extractions (air conditioning settings, accessory loads, etc…)…
>
> In order to reduce "noise" or random fluctuations in the data, ensure the engine parameters are stabilized in the cruise regime of flight (about five minutes after entering cruise mode). The variables should be read separately for each engine and in a reasonable time frame…

In terms of the analysis of the recorded data, the manual stated:

> Optimized feedback will be realized when the data, after having been collected, are processed and analysed on a frequent basis. Therefore P&WC recommends that the data be reviewed on a daily basis wherever possible. However, the data should be analysed at least every five (5) days when the engine is being operated.
>
> **<u>NOTE:</u> Any specific ECTM instructions provided in the applicable engine Maintenance Manual or Service Bulletin will have precedence on the above…**
>
> Delta ITT is the most significant variable, will react to most situations and will show a significant trend on the graph.

[31] The emphasised text in the quotations in this section of the report was also included in the source document.

Delta … Ng… [is] also important and will demonstrate a trend on the graph.

Delta …Wf trend will not always be in evidence on the graph, but the usefulness of the plots is in depicting certain symptoms.

The trend of a healthy engine shows straight lines with only slight deviation (deterioration) over time. If the delta points begin to deviate significantly and in a consistent (gradual) manner from the baseline(s), it is a signal that the engine performance is changing; action needs to be taken to determine the reason(s) and to rectify and re-establish the baseline condition(s).

In terms of guidelines for analysing the data, the manual stated:

NOTE: The following delta net changes are for reference only and can be used with engine operated within P&WC published service intervals. All reference should be made to the relevant Maintenance Manual troubleshooting charts for specific guidelines.

Delta ITT

(1) Net change of 10 to 15° C: Early signal of deterioration that should be investigated when convenient.

(2) Net change of 20 to 25° C: Deterioration becoming more serious. Further running may result in higher cost component replacement, e.g. compressor(s) turbine vane ring and/or compressor(s) turbine blades. Action should be taken as soon as possible.

(3) Net change above 30° C: At this level, whether or not ITT is redlined, deterioration has progressed to a point where serious engine damage is imminent.

Delta Ng…

1) Net change of 0.75 to 1.0%: Should be investigated when convenient.

2) Net change above 1.5%: Action should be taken as soon as possible…

Most engine deterioration is gradual, resulting in progressive changes in delta points. Exceptions to this include hot starts, FOD [foreign object damage], reduction gearbox and compressor… turbine distress; any or all of these may cause a "step" change if sufficiently severe.

The manual also provided general guidelines on interpreting patterns of ECTM data. This information included the following:

- An abrupt change in one parameter is an indication of an instrumentation problem related to that parameter. An abrupt change in all parameters on one engine indicates problems with the measurement of engine torque or propeller speed. An abrupt change in delta Ng and delta ITT on both engines indicates problems with the measurement of outside air temperature or pressure altitude, and an abrupt change in all three parameters on both engines indicates a problem with the measurement of indicated airspeed.
- A gradual increase in delta Ng and delta ITT, with delta Wf remaining steady or increasing, indicates one of the following: a dirty compressor, a slow leak from the compressor case drain plugs or air system, a dirty bleed valve orifice or slow diaphragm leak, or irregularities with the bleed valve base.
- A gradual increase in delta ITT and delta Wf, with a gradual decrease in delta Ng, indicates a hot section problem.
- A sudden increase in delta ITT and delta Ng, followed by a continuing increase in delta ITT and a decrease in delta Ng (and a possible increase in delta Wf), indicates a hot start or momentary fuel nozzle leak.

An earlier version of the manual (5^{th} edition, July 2000) provided the following additional information regarding cold section and hot section problems:

- There are four types of problems that could be encountered with the cold section of an engine: aircraft air intake, dirty compressor, compressor foreign object damage, and air leaks. Such problems reduce the amount of air delivered to the combustion chamber, leading to a loss of power. To regain the power, the airflow needs to be recovered. This requires moving the power lever forward, which increases the fuel flow and causes the compressor to turn faster to compensate. In summary, cold section problems lead to increases in delta Wf, delta ITT and delta Ng.
- Hot section problems include burnt compressor turbine vanes and excessive compressor tip clearance. Such problems reduce the amount of power extracted by the turbine. The compressor needs more power than the turbine can provide, leading to a reduction in compressor speed and power output. Moving the power lever forward increases power and Wf and ITT. Ng increases, but remains below the initial speed. In summary, hot section problems lead to increases in delta Wf and delta ITT, but a decrease in delta Ng.

The following information was introduced into the manual with the 7th edition:

> The operator should be very cautious about the rate of change(s) versus the time interval. A 10°C ITT increase taking place within 2000 hours of operation is considered perfectly normal but the same ITT increase taking place within only a few hundred hours is considered very serious. In this last case, quick action needs to be taken to determine the reason(s) and to rectify and re-establish the baseline condition(s) as soon as possible.

1.17.6 Engine manufacturer's *PT6A-20A Maintenance Manual*

Maintenance conducted on the PT6A-20A engines was required to be conducted in accordance with the engine manufacturer's *PT6A-20A Maintenance Manual*.[32] Part 2 section 7 of the manual contained recommended procedures for engine system troubleshooting. It comprised:

> …a series of diagnostic tests and rectification sequences which will assist the operator in discovering, isolating and correcting various troubles that may arise in the basic engine or any of its related systems during service.

The manual also included a comprehensive fault analysis tree for engines that were, or were not, on an ECTM program, along with a troubleshooting guide and supporting notes. The following information was included in the notes:

> 2. A rapid shift in engine parameters is usually the result of an indicating system defect.
> 3. To extend hot section life, the following preventative maintenance, based on the increase in ITT from the values established at engine installation (engine performance check or ECTM), is recommended:
>   a. For 10° C (20° F) increase in ITT, do a performance recovery wash. In addition, ITT system and engine ground power tests are recommended to ensure reliable engine performance data. Also, test spray pattern or refurbish fuel nozzles.
>   b. For a 15° C (27° F) increase in ITT or a 1 to 1.5% decrease in Ng, do a borescope inspection of the combustion chamber small entry duct, CT [Compressor Turbine] turbine vane and CT turbine blades. In addition, do the maintenance recommended in step (a).

[32] Civil Aviation Regulation (CAR) 1988 r. 42V(1) stated that maintenance must be conducted in accordance with approved maintenance data. CAR 1988 r. 2A(2) stated that 'approved maintenance data' included '…instructions, issued by the manufacturer of aircraft, aircraft components or aircraft materials, that specify how maintenance on the aircraft, components or materials is to be carried out'

In addition to maintenance actions in response to ECTM data, the engine manufacturer's *PT6A-20A Maintenance Manual* also provided a schedule of maintenance activities. For example, a performance recovery wash was 'strongly recommended' every 100 to 200 hours, with the frequency to be adjusted in response to ECTM data.

1.18 The operator's maintenance organisation

1.18.1 Organisational structure

The operator conducted low capacity regular public transport (RPT), passenger charter and flying training operations. The same organisation was the holder of the Air Operator's Certificate (AOC) for the operator's aircraft, the holder of the Certificate of Registration for the aircraft, and the holder of the Certificate of Approval for the maintenance of the aircraft.

The operator was a proprietary limited company and the aviation manager/chief pilot was one of the directors. The maintenance controller reported to the aviation manager/chief pilot. Maintenance work from March 2001 was conducted on the operator's aircraft by a newly formed maintenance organisation owned by the operator. The manager of this maintenance organisation, who was also the chief engineer, reported to the aviation manager/chief pilot. From 3 August 2001, the chief engineer also performed the duties of the maintenance controller.

1.18.2. Operator's fleet

Between January and November 2001, the operator had three Beech Aircraft Corporation King Air C90 aircraft and three other twin-engine aircraft that were powered by PT6A series engines (a Beech Aircraft Corporation Super King Air B200 and two De Havilland Canada DHC-6 aircraft). The C90 aircraft were used for charter operations, and the other three aircraft were used for RPT and charter operations.

The operator's main base was at Toowoomba aerodrome. It also had bases in other locations at various times. The three C90 aircraft were not based at Toowoomba until the end of June 2001. One of the C90 aircraft was not used after the beginning of July 2001. In September 2001, one of the other C90 aircraft was transferred to a newly-started Darwin base.

During the period January to July 2001, the B200 and DHC-6 aircraft conducted a total of approximately 138 flight hours per month and the three C90 aircraft conducted a total of approximately 91 hours per month. During the period August to November 2001, the B200 and DHC-6 aircraft conducted a total of approximately 151 flight hours per month and the two remaining C90 aircraft conducted a total of approximately 63 hours per month. Overall, there was a reduction in the operator's fleet hours of 6 per cent in the period August to November 2001, compared with the period January to July 2001.

1.18.3 Maintenance control

The operator's *Maintenance Control Manual* detailed the requirements for maintaining its fleet of aircraft. The introduction to the part of the manual that applied to C90 aircraft included the following:

> All maintenance carried out on … C-90 aircraft shall be carried out in accordance with the Aircraft Manufacturers and Civil Aviation Regulation requirements.
>
> This Maintenance System is to be used in conjunction with the Beechcraft C-90 Service Manual, Service Bulletins and Instructions and Civil Aviation Orders. The applicable Manufacturer's maintenance publications are to be referred to when appropriate.

Responsibility for the control of maintenance of Class A aircraft (used in public transport operations or certified in the transport category) on behalf of the AOC holder was held by the maintenance controller, in accordance with the requirements of CAR 1988, r. 42ZV. The role of a maintenance controller was to develop, control, organise and supervise all maintenance activities carried out on the aircraft as specified in the *Maintenance Control Manual*. Schedule 9 of CAR 1988 stated that:

> 1.1 To be the maintenance controller a person must:
>
> (a) know and understand the operator's maintenance control manual;
>
> (b) know and understand the requirements of the regulations in relation to the maintenance of aircraft;
>
> (c) demonstrate the required knowledge and understanding for the purposes of being approved as the maintenance controller.

The CARs required a maintenance controller for all Class A aircraft, but not for Class B aircraft (used in charter operations). The maintenance required for Class A aircraft was more rigorous in its application and control than for other Australian civil aircraft. LQH was a Class B aircraft that normally required less rigorous control of maintenance. The operator's maintenance controller at the time of the accident was given an Instrument of Approval from CASA on 17 August 2001. LQH was one of six aircraft listed on the instrument. This meant that the maintenance of LQH had to be managed by the maintenance controller, who was also the chief engineer.

1.18.4 Maintenance scheduling

The operator's system of maintenance for C90 aircraft stated that all maintenance due during the currency of a maintenance release '…shall be listed in the Maintenance Due Section of the Maintenance Release'. There was no evidence that the AD/ENG/5 requirement for performance recovery washes to be conducted every 3 months or 220 hours, whichever came first, had been entered on three recent maintenance releases issued for LQH. This did not include the maintenance release valid at the time of the accident as it was not available.

The operator recorded the completed maintenance tasks for each aircraft in a computerised 'aircraft maintenance certification log'. The operator also had a custom-made computer-based spreadsheet which was used to forecast and schedule all maintenance tasks, including those required by Airworthiness Directives and those specified by the aircraft manufacturer. After maintenance tasks were completed, the maintenance controller would enter confirmation of completed tasks into this 'maintenance notification' spreadsheet, and record the hours and/or calendar date on which the tasks were completed. The spreadsheet would then list, in a separate column, the next time that a maintenance task was due, either in terms of aircraft hours or a calendar date. The spreadsheet did not have a capability for automatically alerting the maintenance controller of upcoming maintenance requirements and it was not electronically linked to the aircraft maintenance certification log.

A printout of the maintenance notification spreadsheet for LQH was obtained by the investigation in the week following the accident (see Appendix C). This printout included a list of items related to AD/ENG/5, including the item 'compressor power recovery wash'. This item was listed on two rows. On the first row, the task was listed as having being completed at 6,772.2 hours (which was the recorded hours as at 7 June 2001) and next due at 6,992.2 hours. On the second row, the item was listed as having being completed on 27 September 2001 and next due at 27 December 2001. Neither row had an annotation regarding which engine these entries referred to. As noted in Section 1.6, there was no record in the aircraft maintenance certification log or other maintenance documentation that a performance recovery wash on either of the engines on LQH was conducted after 7 June 2001 (see Appendix C).

A review of the maintenance notification spreadsheet found several examples where the maintenance tasks had been conducted, but the maintenance notification spreadsheet had not been updated for either the calendar time or hours. This included one airframe maintenance task conducted on 27 September 2001.

1.18.5 Maintenance arrangements prior to March 2001

Until February 2001, the operator's fleet of aircraft was maintained by external maintenance organisations. A review of the maintenance documentation for the period April 1998 to February 2001 indicated that maintenance for LQH was conducted in accordance with applicable schedules and requirements. The operator employed a full-time maintenance controller during this period. This maintenance controller had completed the manufacturer's 3-day training course on ECTM and conducted ECTM for the fleet. In the period 1 January to 7 June 2001, three performance recovery washes were conducted on the left engine. During that time, LQH flew about 197 hours.

On 20 December 2000, the operator lodged an application with CASA for a Certificate of Approval to conduct maintenance on the operator's fleet of aircraft. On 28 February 2001, CASA completed the initial Certificate of Approval assessment of the proposed maintenance organisation. The operator's application proposed that the manager of the organisation would hold the additional position of chief engineer as well as being the sole Licensed Aircraft Maintenance Engineer (LAME). An apprentice was to assist with maintenance tasks. The full-time maintenance controller continued in that position.

The person appointed by the operator as the chief engineer had worked on the operator's aircraft since October 2000, under the supervision of another maintenance organisation. He previously had 17 years military service as an aircraft maintenance engineer. That experience included working on B200 and DHC-6 aircraft, both of which were powered by PT6A series engines. He held a civilian LAME qualification that included a group rating for PT6A series turbine engines, and he had experience in supervisory roles during his military service.

1.18.6 Maintenance arrangements March to August 2001

On 9 March 2001, CASA issued the initial Certificate of Approval for the proposed maintenance organisation for a 6-month period, expiring on 30 September 2001 (see Section 1.19 for further information on CASA's approval of the maintenance organisation). An aircraft maintenance engineer (AME) joined the organisation in March 2001.

1.18.7 Maintenance arrangements August to November 2001

The full-time maintenance controller resigned on 3 August 2001. The chief engineer was then approved by CASA to be the operator's maintenance controller. No additional maintenance staff were added to the maintenance organisation during this period. The previous maintenance controller's resignation was relatively sudden, leaving only a short time for the chief engineer to be briefed on his new duties. However, the previous maintenance controller offered to provide ongoing advice to the chief engineer regarding his new duties. CASA's process for approving the chief engineer as the maintenance controller is discussed in Section 1.19.5.

1.18.8 The operator's engine data recording process

The procedures for pilot recording of engine trend data was detailed in Part B of the operator's *Operations Manual* as follows:

> 6.1.8. TREND MONITORING
>
> Briefly, overhauls of PT6/A engines installed on company King Air C90 (PT6A-20 engines) aircraft have been approved for overhauls on an "on condition" basis. To achieve this a number of engineering requirements have been specified. One of these is the level at which engine parameters are recorded for the trend monitor.
>
> Parameters recorded at random levels show spikes and variances, which are unacceptable. It has been determined that the readings taken between flight level FL110 [11,000 ft] and FL180 [18,000 ft] (inclusive) are satisfactory.
>
>> Engine parameters are to be recorded once each day.
>>
>> (Engine starting peak ITT for the first start of day).
>
> They are to be recorded between FL110 and FL190 (inclusive), when established in the cruise for at least 5 minutes for the engine parameters to stabilise.
>
> Recording of trend data should not be made with abnormal engine settings this includes ice vanes being extended. Alternatively trend data may be recorded if all abnormal setting are noted on the trip sheet.
>
> They do not have to be recorded on the first flight of the day, but on a convenient sector at the levels indicated above.
>
> If operational requirements preclude flight at the above levels then the occasional missed recording is acceptable. However, consistent trend monitoring is a mandatory requirement for the application of "on condition" overhauls. It should be a rare day when a trend cannot be recorded.

A review of the flight logs for LQH and the operator's other two C90 aircraft found that from January until the end of July 2001, trend data was recorded on 87 per cent of the days on which the aircraft were flown. Between 1 August and the accident date, that rate was 61 per cent. Over the same timeframes, the rate of pilot recording for LQH fell from 95 per cent to 52 per cent. There were occasional flights when it was not possible to record trend data due to the nature of the flight, such as its limited duration at cruise or that it was flown at an altitude outside of the range specified in the operator's manual. However, the flight logs revealed that there were many opportunities for the data to be recorded on days when it was not recorded. The maintenance controller who resigned in August 2001 reported that he often had to remind pilots of the need to record trend data.

1.18.9 ECTM data for LQH

Figures 15 and 16 present the output produced by the engine manufacturer's ECTM software program for the recorded trend data for the left and right engines of LQH from 21 May to 21 November 2001. The same output is presented in a simpler form in Appendix D. The three columns of data refer to the delta values and trend values for fuel flow (Wf), inter-turbine temperature (ITT) and compressor speed (Ng). The trend line values are shown as 'X', and the delta values are shown as 'W', 'T', and 'N' as relevant. The date of the flight for each of the delta values is shown on the left of the figure. The centre line of the five vertical lines for each parameter represents the baseline value. The numbers above the vertical line show the magnitude of the delta values represented by the other vertical lines. For both engines, the row of '#' symbols shows when the baseline was reset following the last maintenance activity on

7 June 2001. Baseline values were therefore not established until 15 data points later on 4 July 2001.

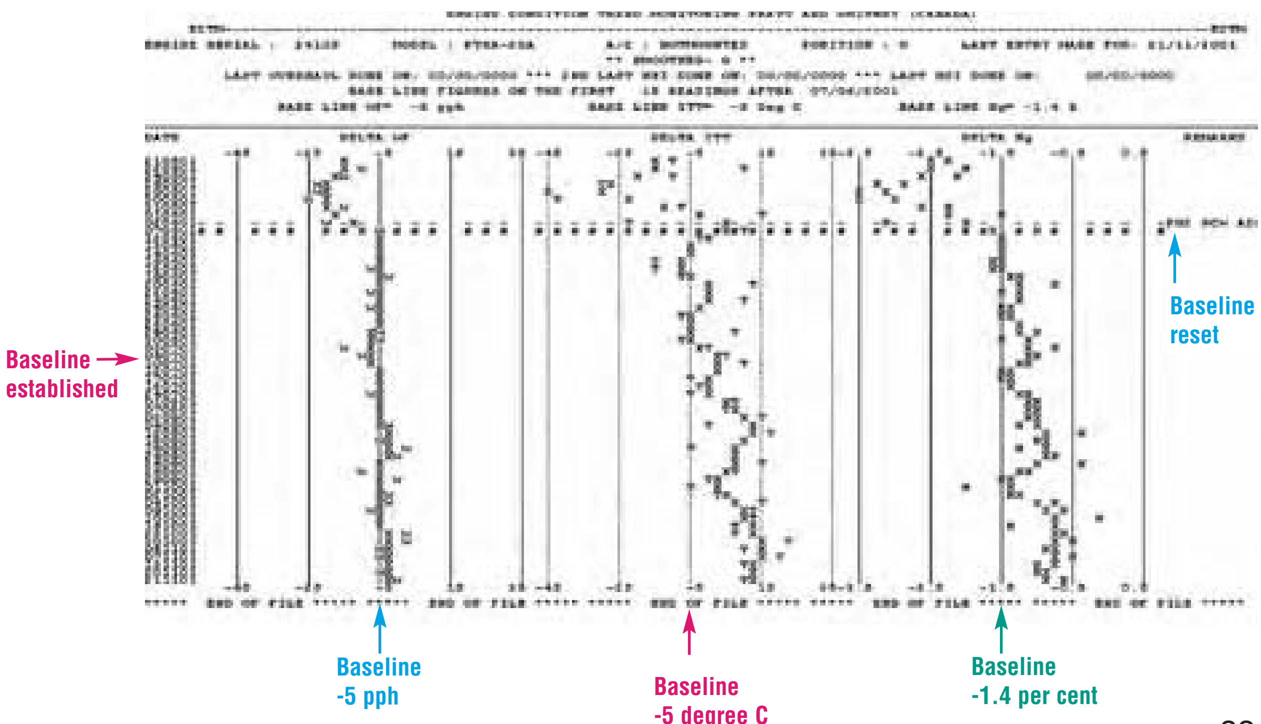
The data pattern for the left engine showed a gradual increase in the delta ITT trend line after the baseline was established. The delta ITT trend line reached 10 degrees above baseline on 1 August 2001 (see Figure 15). As noted in Section 1.17.1, the trend line is based on data points before and after a particular data point of interest. As discussed in Section 1.18.10, an external party had access to the data for LQH after 7 August 2001 and after 12 September 2001. The investigation reviewed the trend lines using only the data up to and including 7 August 2001 entered into the program. In that case, the delta ITT trend line reached about 8 degrees above baseline. Using data only up to 12 September 2001, the delta ITT trend line reached almost 20 degrees above baseline.

One data point in these sets of data, recorded on 3 September 2001, should not have been included as it was recorded at less than 8,000 ft and outside of the normal range of altitudes required by the operator for data recording (see Section 1.18.8). This value was not excluded prior to the trend lines in Figure 15 being developed. The delta value of ITT on the left engine for the 3 September data point was relatively high (21 degrees above baseline). When this data point was removed from the data set, the trend line for delta ITT as at 12 September (with all data after that date excluded) reached a level of about 12 degrees above baseline.

The increase in delta ITT of over 10 degrees from 7 June to 12 September 2001 occurred over 68 engine hours. The increase reached 20 degrees above baseline by late October 2001. There were about 129 engine hours from 7 June to 30 October 2001. The removal of the 3 September data point had a negligible influence on the delta ITT values in October.

The delta Ng trend line followed a similar pattern to the delta ITT trend line. It reached 0.5 per cent above baseline by 12 September, and reached 0.75 per cent above the baseline by late October. There was a small increase over time in the trend line for Wf.

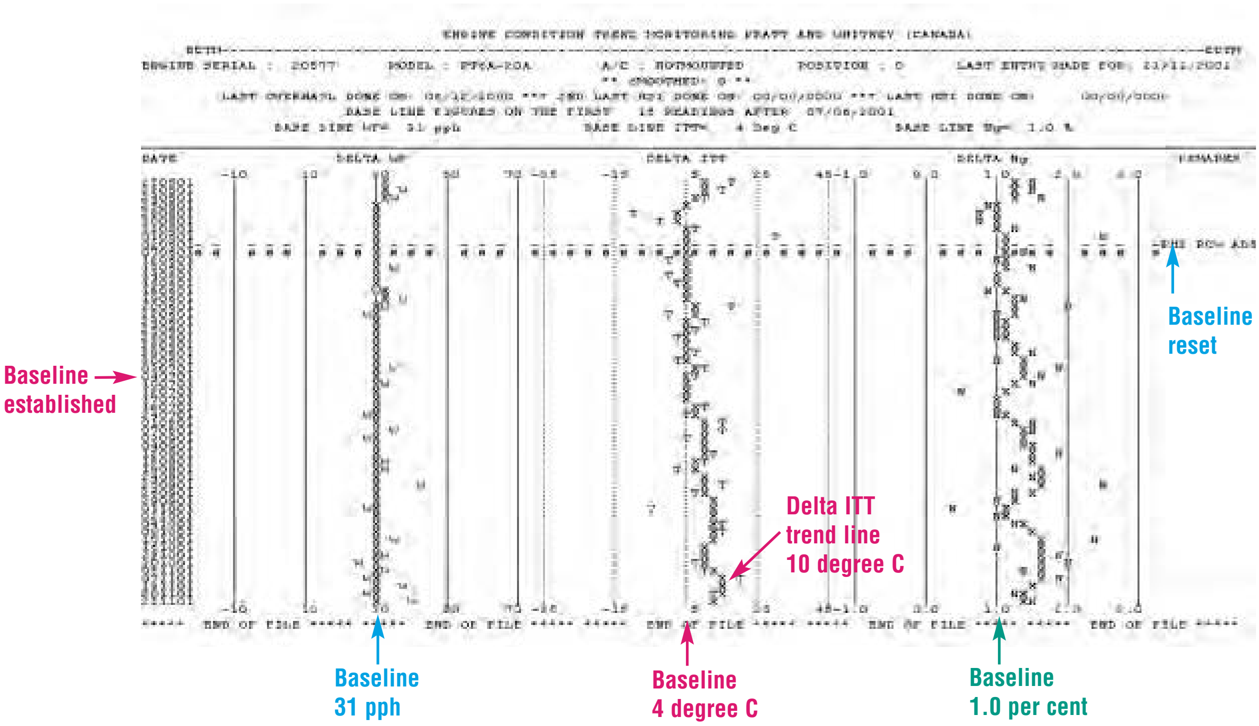
FIGURE 15:
Left engine ECTM data



The data pattern for the right engine showed a gradual increase in the delta ITT trend line, which reached 10 degrees above baseline in November 2001 (see Figure 16). The delta Ng trend line was variable, but also appeared to show an upward trend over time and had values of over 0.5 per cent above baseline in November 2001. There was no change in the Wf trend line.

The data patterns for the left engine showed a temporary decrease in delta ITT and delta Ng in late September/early October. The data pattern for the right engine showed a similar trend, with a temporary decrease in delta Ng and ITT remaining constant. The investigation noted that the data recorded for 1 October provided values for delta ITT and delta Ng for both engines that were very low compared to other values for these parameters in the weeks before and after this date.

FIGURE 16:
Right engine ECTM data



1.18.10 The operator's ECTM data analysis process

In accordance with the Civil Aviation Regulations (CARs)[33], the operator was to ensure that the person holding the position of maintenance controller properly carried out the required functions, which included the responsibility for ensuring compliance with AD/ENG/5 Amendment 7. This did not mean that the maintenance controller himself had to conduct particular tasks such as ECTM analysis, but it was his responsibility to ensure that those tasks were accomplished in accordance with the relevant requirements.

When the operator commenced internal maintenance on its aircraft in March 2001, the then maintenance controller had completed the engine manufacturer's ECTM training and conducted ECTM for the operator's aircraft. The requirements specified in AD/ENG/5

33 CAR 1988 r. 42ZY(2)(a), CAR 1988 Schedule 9, paragraph 2.1 (a).

Amendment 7 were therefore met. Although he resigned on 3 August 2001, he continued to conduct ECTM data analysis for the operator's aircraft until 6 August 2001.

The operator's chief engineer, who was the maintenance controller at the time of the accident, had not completed the engine manufacturer's ECTM training course, but was conducting tasks associated with ECTM such as data entry (see Section 1.17.4). As such, after 6 August 2001, the maintenance of the PT6A-20A engines did not comply with the requirements of AAC 6-29 Amendment 1, and therefore the requirements of AD/ENG/5 Amendment 7.

The chief engineer reported that he believed he could gather and enter the trend data, but that it had to be analysed by an individual who had completed ECTM training. He indicated that, during August 2001, he had negotiated an informal arrangement with a field representative from the engine manufacturer's local office to analyse the ECTM data, until such time as he was able to attend the appropriate training course and become qualified. The chief engineer indicated that he had attempted to arrange ECTM training, but the courses were fully booked and despite many attempts, he was unable to attend a course until March 2002. The engine manufacturer's office in south-east Queensland confirmed that three ECTM courses were conducted each year in Australia and that these courses were fully subscribed during the period in question. The local CASA office confirmed that it was aware of the arrangement between the chief engineer and the field representative (see Section 1.19.7).

The chief engineer and the engine manufacturer's field representative agreed that the chief engineer would regularly e-mail the trend data to the engine manufacturer's field representative for analysis. No formal arrangement was in place.

The chief engineer told the investigation team that he had been sending the trend data to the field representative approximately every 2 weeks for analysis. On several occasions during the investigation, the ATSB requested evidence of those communications, but none was provided.

The field representative reported that the provision of ECTM data from the chief engineer was infrequent. The field representative provided the ATSB investigation team with copies of the ECTM data that he said had been sent to him by the chief engineer between August and November 2001. This included three sets of data; one sent on 27 August, one sent in September, and the other on 2 November. The 27 August set included data for the engines on LQH, with the last data point being for a flight on 7 August 2001. The September set included data for the engines on LQH, with the last data point being for a flight on 12 September 2001. The 2 November set contained trend information for two engines that were from the operator's B200 aircraft, but did not include any data from either engine fitted to LQH.

The chief engineer indicated that he had been relying to a large extent on feedback from the field representative regarding any maintenance action that was required in response to the trend data. From time to time, he had received recommendations concerning procedures to be conducted on particular engines but could not recall receiving any information regarding the engines on LQH. He advised that he had never received any feedback from the engine manufacturer's field representative regarding the quality of the data he was providing, or the frequency with which he was providing it. In the absence of any feedback from the engine manufacturer's field representative regarding LQH, his view had been that no maintenance action was required.

The engine manufacturer's field representative advised that the arrangement to analyse the ECTM data was conducted as an informal gesture of assistance within the bounds of his role to provide customer support. He believed that the primary task of evaluating the data still belonged to the operator. Although he had agreed to carry out ECTM analysis, his understanding was that the onus was on the operator to provide the ECTM data for analysis. The field representative advised that he reviewed the data he had been provided with on the operator's engines and provided feedback by telephone to the chief engineer on several occasions. He could not specifically recall whether he had contacted the chief engineer with any feedback regarding trend data for LQH. He added that, if he had identified any discrepancy in the trend data, he would have communicated the details to the chief engineer. He also noted that he would not usually remove any data points from consideration that were outside the flight level tolerances, because the smoothing function of the software program catered for outlier values.

Following the accident, the operator provided the investigation with trend data for the engines that were fitted to LQH at the time of the accident, including data for the flight immediately preceding the accident flight. That data formed the basis for examining the performance of the engines in the period leading to the accident (see Section 1.18.9).

1.18.11 Maintenance resources and workload issues

Aircraft manufacturers provide detailed information for the maintenance of their product or component throughout its service life to ensure that aircraft performance and reliability levels are maintained. Manufacturers' maintenance requirements are published as a series of separate activities for both scheduled and unscheduled maintenance tasks. Each task requires certain resources, both material (such as replacement parts) and maintenance personnel. Maintenance activities can be examined and calculations performed to determine the number of maintenance hours required per flight hour (MH/FH). This type of data enables organisations to make accurate estimates about the number of maintenance personnel required to properly maintain a fleet of aircraft.

During the investigation, the aircraft manufacturer advised that it did not produce MH/FH figures for out-of-production aircraft, such as the C90. However, a number of consultancy organisations based in the US provided operating costs such as maintenance labour expense per flight hour for a range of different aircraft types. The investigation obtained basic data from two consultancy organisations.[34] Both organisations produced similar sets of data. For example, for the C90 aircraft, one organisation[35] estimated a MH/FH ratio of 2.0 (excluding all engine maintenance work), and the other organisation[36] estimated a ratio of 2.6 (including all engine maintenance except overhauls and mid-life inspections).[37]

For indicative purposes, the investigation used data from the two consultancy organisations to calculate the maintenance labour required for conducting the scheduled and unscheduled maintenance on the operator's six twin turboprop aircraft for the periods January to February 2001 (before the operator commenced conducting maintenance internally), March to July 2001 (after the operator commenced internal maintenance), and August to November 2001 (after the chief engineer became maintenance controller). Based on this data, the investigation calculated that the equivalent of at least three maintenance personnel was probably required to conduct the expected maintenance labour (scheduled and unscheduled) for the operator's fleet during

34 The two organisations produce estimates for the average maintenance labour cost per flying hour based on the experience of a range of operators in the US using the relevant aircraft type(s).

35 Conklin and deDecker Aviation Information (see www.conklindd.com).

36 Aviation Research Group/U.S., Inc (ARGUS) (see www.aviationresearch.com). ARGUS figures for a number of aircraft have also been produced in the August editions of the industry magazine, *Business & Commercial Aviation*, in recent years.

37 ARGUS 'flight hours' are based on the time from engine start to engine shutdown whereas normal convention is to use liftoff to touchdown time. The ARGUS quoted ratio of 2.1 was multiplied by 1.22 to make the ARGUS figures consistent with the other consultancy organisation and also the operator's flight hours. This factor was based on a review of flight hours and engine start to shutdown times of the operator's three C90 aircraft during 2001.

the first two periods, and at least 2.75 maintenance personnel was probably required in the last period. These estimates included all labour except engine overhauls. They did not include the duties associated with the maintenance controller position.

Other relevant information concerning the maintenance resources required to conduct the maintenance tasks for the operator's aircraft included the following:

- During the period January to June 2001, the three C90 aircraft were based away from Toowoomba and some unscheduled maintenance work was conducted by personnel external to the operator. In general, unscheduled maintenance would form only a small component of the overall maintenance labour required for a particular aircraft (estimated to be less than 10 per cent).
- From September 2001, one of the C90 aircraft was based in Darwin and maintenance was conducted in that location by an organisation external to the operator. Maintenance work was completed on the aircraft in Toowoomba in August before the aircraft was transferred to Darwin. The expected maintenance labour associated with this aircraft was probably equivalent to about 0.5 maintenance personnel. However, the chief engineer was still responsible for liaising with this external organisation, overseeing its work and performing the maintenance controller functions.
- Radio and instrument electrical maintenance was performed by an external maintenance organisation. In general, scheduled maintenance in these areas would only form a minor component of the overall maintenance required for a particular aircraft.
- During the investigation, the chief engineer also reported that, on some occasions, other aircraft maintenance personnel would also assist with maintenance work on a non-contracted, casual basis. A review of the maintenance worksheets indicated that the level of usage of such additional resources was minimal prior to the accident.
- In general terms, an apprentice would not be considered to represent a full maintenance person for the purposes of evaluating maintenance labour requirements, particularly a first year apprentice. Similarly, an AME would require supervision and not be able to conduct all required tasks. The investigation estimated that, together, these two employees would be equivalent to about 1.25 maintenance personnel.

The chief engineer advised the investigation team that, prior to August 2001, he worked long hours in the hangar, his workload was intense, and 10 to 12 hour days and six-day weeks were not unusual. After August 2001, he advised that there was a decrease in the operator's flying activity, and he spent less time working on the aircraft and more time conducting maintenance controller duties.

1.19 Regulatory oversight of maintenance

1.19.1 Functions of CASA

Section 9 of the *Civil Aviation Act 1988* was titled 'CASA's functions' and included the following:

> (1) CASA has the function of conducting the safety regulation of the following, in accordance with this Act and the regulations:
>
> (a) civil air operations in Australian territory;
>
> (b) the operation of Australian aircraft outside Australian territory;
>
> by means that include the following:
>
> (c) developing and promulgating appropriate, clear and concise aviation safety standards;

(d) developing effective enforcement strategies to secure compliance with aviation safety standards;

(e) issuing certificates, licences, registrations and permits;

(f) conducting comprehensive aviation industry surveillance, including assessment of safety-related decisions taken by industry management at all levels for their impact on aviation safety;

(g) conducting regular reviews of the system of civil aviation safety in order to monitor the safety performance of the aviation industry, to identify safety-related trends and risk factors and to promote the development and improvement of the system;

(h) conducting regular and timely assessment of international safety developments.

Section 9A of the Act was titled 'Performance of functions' and paragraph (1) stated:

> In exercising its powers and performing its functions, CASA must regard the safety of air navigation as the most important consideration.

The International Civil Aviation Organization (of which Australia is a member State) published manuals pertaining to the manufacture, operation and maintenance of aircraft by member states. Volume 1 of the *Airworthiness Manual* (Doc 9760, AN/967) outlined the obligations of the State of Registry and the State of Operator under the Convention on International Civil Aviation on matters related to airworthiness. The Manual stated that one of the functions of an airworthiness organisation, such as CASA, was:

> …monitoring of service bulletins from the manufacturer to determine likely effects on the design and continuing airworthiness of the aircraft and powerplant and to decide steps to be taken to avoid or correct difficulties. If as a result of this activity, it is decided that an inspection or modification is necessary to ensure continuing airworthiness of the aircraft, a firm and positive direction (in the form of an airworthiness directive) should be published and directed to all operators…

The CARs empowered CASA to issue airworthiness directives. CAR 1998 r. 39.001, issued in 1999, stated the following:

> (1) CASA may issue an airworthiness directive for a kind of aircraft, or a kind of aeronautical product, if:
>
> (a) an unsafe condition exists in an aircraft or aeronautical product of that kind; and
>
> (b) the condition exists, or is likely to exist, or could develop, in other aircraft or aeronautical products of that kind.

These mandatory directives had precedence over manufacturers' and operators' publications, which were not legally binding unless they were incorporated into an airworthiness directive or the aircraft's system of maintenance or directed by CASA.

1.19.2 Development of AD/ENG/5

AD/ENG/5 was initially introduced in May 1985. The initial version specified required TBO intervals for all turbine engines in use in Australia at that time. Amendment 1 (November 1989) required that all turbine engines be overhauled at periods not exceeding those recommended by the manufacturer or as approved by the Authority.

Amendment 2 (December 1992) allowed PT6A engines installed in aircraft operated solely in the Agricultural Category to be overhauled at periods not to exceed 5,000 hours, as long as certain requirements were met. CASA advised that Amendment 2 was introduced to give small agricultural operators an additional option for meeting overhaul requirements. Previously they were required to overhaul the engines according to a fixed interval, or in accordance with a sampling system as outlined by the manufacturer (see also Section 1.17.2). For an operator with a small number of engines, such a sampling system did not provide much opportunity for extending TBOs for the fleet.

After Amendment 2 was introduced, a number of non-agricultural operators with small fleets expressed interest in also extending TBOs and reducing operating costs. Amendment 3 (June 1993) allowed PT6A engines in all aircraft to be overhauled at periods not exceeding 5,000 hours as long as certain requirements were met. The requirements were more detailed and onerous than those listed in Amendment 2. The requirements were similar to recommendations specified in the manufacturer's maintenance manuals, but introducing them into the AD made them mandatory requirements for operators who elected to extend their TBOs to 5,000 hours.

During the investigation, CASA advised that the option to increase the TBO to 5,000 hours had the potential to significantly reduce operating costs without degrading airworthiness. Factors supporting the introduction of the option included:

- There was sufficient evidence of PT6A-20A engines operating on life development/extension programs in Australia from 1966 to suggest that those engines could operate for 6,000 hours and even 7,000 hours with no compromise to safety, while remaining reasonably economical to operate.
- The engine manufacturer supported overhaul periods of up to 8,000 hours in some aircraft and categories of operation. CASA considered 5,000 hours as a balance against the lower levels of maintenance experience that could exist in some organisations.

Amendment 3 was introduced after discussions with the engine manufacturer and a number of operators and maintenance organisations.

Later amendments to AD/ENG/5, including Amendment 7, were essentially the same as Amendment 3 in terms of the requirements for allowing a TBO of 5,000 hours for PT6A engines.

During the investigation, CASA advised the following:

> Engine manufacturer, Pratt and Whitney Canada, allows for extension of TBO, in 500 hour increments, starting from a base line of 3600 hours, for operators based on samples of engines submitted for detailed analysis and review. This procedure disadvantages operators with small fleets as it could take inordinate number of hours and engine overhauls before they could attain a 5000 hours TBO.
>
> The Civil Aviation Act, paragraph 9 (1) (c) empowers CASA to promulgate "appropriate, clear and concise aviation safety standards" so that the advantages of extended TBO are available to all operators subject to certain mandatory maintenance actions including ECTM. AD/ENG/5 Amendment 7 was issued to achieve this objective. This Airworthiness Directive is no different from other Directives issued by CASA and in all instances requires mandatory compliance.

CASA also advised that 'AD/ENG/5 was only setting a maintenance standard rather than addressing an immediate unsafe condition, as in the case of most other ADs'. It also advised that, at the time of issuing the AD, there was no other mechanism for introducing maintenance standards.

During the investigation, CASA also advised the following in regard to what maintenance actions were required if an operator elected to utilise AD/ENG/5 to extend engine TBOs to 5,000 hours:

> There is essentially no difference between the maintenance requirements mandated by CASA and that required by the manufacturer.
>
> As the manufacturer has no power to mandate maintenance actions, it insists on the establishment of the enhanced maintenance practices by the operator prior to allowing a TBO extension.
>
> However, CASA mandates the requirements if the operator elects the 5000-hour TBO option. It is important to emphasise that CASA does not mandate the 5000-hour TBO; it is only an option for the operator subject to certain mandatory requirements. The maintenance requirements for AD/ENG/5 are no less restrictive compared to that specified by the manufacturer for TBO extension.

1.19.3 Overview of CASA oversight process

CASA's oversight of maintenance organisations consisted of two main processes: assessing suitability for a Certificate of Approval and surveillance. The CASA process for issuing a Certificate of Approval to maintenance organisations was outlined in its *Certificate of Approval Procedures Manual*. The manual consisted of some general guidelines for CASA inspectors, and a series of forms asking specific questions for inspectors to consider when making their assessments.

Until recent years, CASA's approach to surveillance was outlined in its *Aviation Safety Surveillance Program (ASSP) Manual*. The manual was introduced in May 1994, with the last version (version 4.0) issued in May 1999. In terms of the surveillance of Certificate of Approval holders, the manual consisted of some general guidelines for CASA inspectors, and a series of forms or checklists asking specific questions for inspectors to consider when making their assessments. Forms were provided on a range of topics, such as organisational structure, procedures, resources and maintenance control.

The ASSP manual was based on a product audit approach, which focussed on inspecting the end-product of a system. CASA's compliance branch staff reported that the ability of the traditional product-based approach to identify safety deficiencies was limited.[38] Accordingly, in the late 1990s, CASA began developing and implementing a systems audit approach, which replaced the ASSP manual. This approach commenced for airline flight operations in mid 1999, and for airline maintenance organisations in mid 2000.

The framework for the new surveillance approach consisted of a list of audit elements. For Certificate of Approval holders, this list consisted of 37 items, including management responsibility, safety policy, handling and storage, maintenance planning/resource control, and aircraft maintenance. Not all of the elements were relevant to all Certificate of Approval holders. While only a selection of the relevant elements were required to be audited at any time, CASA staff were required to audit each relevant element within each 3-year period. CASA compliance branch staff had previously reported to the ATSB (in September 2000) that they would be

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[38] CASA's surveillance approaches have been discussed in recent ATSB investigation reports, including (a) Investigation report 199904538 (Boeing 747-438, VH-OJH, Bangkok Thailand, 23 September 1999), and (b) Aviation Safety Investigation report 20010005 *(Investigation into Ansett Australia maintenance safety deficiencies and the control of continuing airworthiness of Class A aircraft).*

developing broad guidelines for each of the audit elements. At the time of the accident, these guidelines had not been provided to inspectors.

CASA inspectors in the office responsible for the oversight of the operator revealed that they had relied on a variety of source documents to create their own lists to define the scope of each element and identify the issues to audit. These source documents included ASSP forms, US Federal Aviation Administration (FAA) lists, and lists that had been created by individual inspectors.

1.19.4 CASA oversight of the operator

As discussed in Section 1.18.6, the operator obtained a Certificate of Approval to conduct the maintenance of its own fleet of aircraft on 9 March 2001. CASA inspectors noted no problems with the planned organisational structure and level of resources for the operator's maintenance organisation.

Other events relating to CASA's oversight of the operator's maintenance activities that occurred in the period from March to November 2001 included the following:

- **3 August 2001.** The operator's maintenance controller resigned. CASA then approved the operator's chief engineer as the maintenance controller from 3 August 2001 until midnight on 17 August 2001 (see Section 1.19.5).
- **17 August 2001.** The chief engineer was approved as the permanent maintenance controller for the operator for its six twin (turbine) engine aircraft, including LQH. This approval was made after the chief engineer completed an examination and attended an interview with CASA.
- **20-23 August 2001.** CASA conducted a scheduled audit of the operator and the operator's maintenance organisation. Requests for Corrective Action (RCAs) were issued in relation to operational and maintenance issues. The RCAs relating to maintenance issues included:
    1. There was no deputy maintenance controller, a position required by the operator's *Maintenance Control Manual.*
    2. The records for recurring airworthiness directives and recurring maintenance control were not being kept up to date. CASA noted that tracking of these functions was conducted by means of a 'computer generated maintenance forecast', and that this process needed to be documented in the operator's manuals and approved by CASA under CAR 1988, r. 50B.

    A number of the audit observations dealt with the operator's maintenance manuals, including an observation that the manuals did not refer to the current amendment of AD/ENG/5. As a result, CASA recommended that the operator conduct a comprehensive review of the documents. The audit report also noted that the operator had had a downturn in flying activity resulting from the loss of two contracts.
- **19 September 2001.** The operator provided CASA with a written summary of its actions in response to the RCAs issued as a result of the August audit. In relation to the RCA concerning deputy maintenance controller, the operator proposed to train an assistant on data input processes when the maintenance controller was absent. In addition, the operator proposed to remove the position of deputy maintenance controller from its manual. In relation to the RCA on maintenance control, the operator proposed to start transferring information from the computerised 'aircraft maintenance certification log' to the aircraft log books and keep the log books up to date, and to then seek approval from CASA for the computerised recording process.

- **25 September 2001.** CASA noted that the operator's response to all but two of the maintenance-related RCAs was accepted. Further response to two of the RCAs was requested, including the RCA relating to the deputy maintenance controller. The RCA relating to maintenance control was accepted.
- **30 September 2001.** The operator's Certificate of Approval expired (see Section 1.18.6). There was no communication from either the operator or CASA with regard to this matter. The operator's Certificate of Approval had been mistakenly annotated in the CASA database as being valid for 12 months. For that reason, no reminder regarding the imminent expiry of the Certificate of Approval was provided to the operator. Similarly, the need to audit the operator for the renewal of the Certificate of Approval went unnoticed by CASA.
- **23 October 2001.** CASA reminded the operator in writing that two maintenance-related RCAs, issued as a result of the August audit, remained outstanding (these RCAs were eventually acquitted by CASA on 24 December 2001).
- **21 November 2001.** The chief engineer contacted CASA by telephone regarding the expired Certificate of Approval.
- **22 November 2001.** CASA issued the operator with a renewed Certificate of Approval valid until 30 April 2002. The certificate was renewed on the basis of the telephone communication from the chief engineer. No on-site surveillance was conducted. At that time, CASA noted that the operator's maintenance personnel included one LAME (who was also the maintenance controller, the maintenance organisation's manager and chief engineer), one AME, and one apprentice.

1.19.5 Assessment of managers of maintenance organisations and maintenance controllers

CAR 1988 r. 30(1) stated that a person wishing to engage in the maintenance of aircraft was required to apply for a certificate of approval. CAR 1988 r. 30(2B) stated that CASA must have regard to a number of issues when assessing whether or not to grant a certificate. These issues included the relevant qualifications of the applicant and the applicant's employees. The ASSP manual and the *Certificate of Approval Procedures Manual* contained no guidelines on the criteria, qualifications or competencies that CASA staff should consider when evaluating the suitability of a person to act in a managerial role for a maintenance organisation.

During the investigation, CASA personnel advised that there were no defined competencies or required training courses for maintenance controllers. CASA staff were provided with a form that listed 10 general factors that inspectors should consider when assessing an applicant's suitability. Those factors included the applicant's working background, knowledge of relevant regulations, knowledge of the operator's maintenance control manual, and knowledge of maintenance planning and scheduling. There was no requirement to consider the applicant's workload or other duties and responsibilities when considering suitability for the position. The form for the appointment of the operator's chief engineer as maintenance controller for a 2-week period was completed on 3 August 2001 and was based on a telephone interview with CASA.

Other than the checklist, there were no tools or guidelines available to assist inspectors in making assessments of the suitability of an applicant to be a maintenance controller. Several local inspectors had developed written tests or assessment protocols for applicants to complete as part of their assessment of the applicant's suitability. The chief engineer successfully completed a written examination on 17 August 2001. The examination consisted of questions relating to relevant regulations and questions on the operator's *Maintenance Control Manual.*

In recent years, CASA developed guidance information for chief pilot applicants, and provided detailed guidance information for inspectors to assist them to assess the suitability of applicants for a chief pilot position.[39]

1.19.6 Assessment of maintenance staff resources

Section 28 of the *Civil Aviation Act 1988* stated that CASA must issue an operator with an AOC if and only if CASA is satisfied about certain matters. These matters included '…the organisation has a sufficient number of suitably qualified and competent employees to conduct or carry out the AOC operations safely'.

Both the ASSP manual and the *Certificate of Approval Procedures Manual* contained forms which asked CASA inspectors to consider whether a maintenance organisation had sufficient staff to conduct the required maintenance activities. CASA inspectors reported that CASA had no standard guidelines on how to make this assessment. They also reported that they did not use any specific formula, industry data or processes to assess whether the maintenance organisation had sufficient maintenance personnel. They noted that it could be difficult making such assessments because many organisations contract out some of their tasks.

1.19.7 Oversight of ECTM programs

In a section titled 'Reviewing documents', the ASSP manual listed a series of documents it suggested may need to be reviewed prior to conducting an audit on a maintenance organisation. These documents included 'Life extension programs: Details, conditions and limitations'. The investigation found no other specific references to life extension or engine condition monitoring programs in the ASSP manual, *Certificate of Approval Procedures Manual*, or the audit element list for the new systems approach to surveillance.

A review of CASA documents indicated that CASA was aware that all of the turbine engines in the operator's fleet were being operated on an extended TBO as permitted by AD/ENG/5, meaning that an ECTM program was required for all engines. A CASA file note, from a scheduled audit of the operator in January 1999, advised that particular attention was given to the TBO status of all PT6A engines fitted to the operator's aircraft, and whether the engines were eligible for the 5,000 hour TBO under AD/ENG/5.

The left engine for LQH had completed 178.6 hours since the last hot section inspection when the aircraft was placed on the Australian civil register. The engine manufacturer specified that an ECTM program was to be started within 100 hours of a hot section inspection or an engine overhaul (see section 1.17.5). When CASA reviewed the TBO status of the operator's engines in January 1999, this discrepancy was not noted.

During the investigation, CASA confirmed that it was aware that the maintenance controller had an arrangement with the engine manufacturer's field representative for analysis of the ECTM data. CASA advised that it had checked the matter with the field representative, who confirmed that such an arrangement was in place. CASA was aware that the field representative had undertaken ECTM training, and understood that the field representative was carrying out the ECTM analysis as an employee of the engine manufacturer, rather than via an informal or personal arrangement with the operator. No record of that confirmation was found on CASA files. There was no record of any follow-up check on the functioning of the arrangement and the frequency at which engine trend data was being forwarded for analysis.

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39 The ATSB has previously commented (ATSB Report 200100348) on CASA's processes for approving chief pilots, noting that CASA had not formally specified required qualifications or competencies in terms of management or knowledge of systems safety concepts.

When deficiencies identified by the investigation in the operator's ECTM program were brought to the attention of CASA, CASA reviewed the ECTM data for the operator's other turbine engines. It noted that the data for some of the engines indicated a need for maintenance of engine indication systems, and that the operator's engines did not appear to have been maintained in response to data shifts in recent times. CASA also reviewed the engine condition monitoring processes used by several operators in the Queensland region. It found that several of those operators were not conforming to the relevant requirements. During the investigation, CASA reported that it could not advise how many operators in other areas of Australia were identified as not complying with relevant engine condition monitoring requirements as a national review had not been conducted.

1.20 Aircraft performance

1.20.1 Certification standard

LQH was manufactured in the US and was certificated to the standards of the US Civil Air Regulations Part 3 in the Normal Category.[40] Under these design standards, the C90 aircraft was required to achieve, with one-engine inoperative, '…a steady rate of climb…'.[41] To achieve this one-engine inoperative climb performance, the specified aircraft configuration included the following: the remaining engine operating at not more than maximum continuous power; the inoperative propeller in the minimum drag position; the landing gear retracted; and the wing flaps in the most favourable position. For the C90 aircraft this configuration would have required the left propeller to be feathered and the landing gear and wing flaps retracted.

As part of the aircraft's certification process, the aircraft manufacturer conducted flight and ground tests to provide performance data and to establish airspeeds for safe operation (see Section 1.20.5). When LQH was imported into Australia in 1998, CASA accepted the US certification as the basis for certification in Australia.

1.20.2 Australian weight and performance limitations

The performance limitations for C90 aircraft conducting charter operations in Australia were contained in Civil Aviation Order (CAO) Part 20, Section 20.7.4, *Aeroplane Weight and Performance Limitations – Aeroplanes not above 5700 kg – Private, Aerial Work (excluding agricultural) and Charter Operations.*

The take-off climb performance requirements contained in CAO 20.7.4 were for all engines operating at take-off power. The CAO did not specify any performance requirements for the take-off climb with an engine inoperative. For the en-route climb phase, the CAO required LQH to:

> …have the ability climb with a critical engine inoperative at a gradient of 1% at all heights up to 5,000 feet in the standard atmosphere in the following configuration:
>
> (a) propeller of inoperative engine stopped;
>
> (b) undercarriage… and flaps retracted;

40 The term Normal Category applies to aircraft, which '… are intended for nonacrobatic, nonscheduled passenger, and nonscheduled cargo operation'.

41 The one-engine inoperative rate of climb was expressed in the US Civil Air Regulation as being '… at least 0.02 V_{SO} 2 in feet per minute at an altitude of 5,000 feet with the critical engine inoperative …'. The critical engine is that engine which, if it fails, will most adversley affect the performance or handling qualities of the aircraft. The left engine is the critical engine for a C90 aircraft. V_{SO} was 'the stalling speed or minimum steady flight speed in the landing configuration'.

(c) remaining engine(s) operating at maximum continuous power;

(d) airspeed not less than 1.2 V_s.[42]

These certification requirements referred to an 'inoperative' engine. It should be noted that if an engine malfunctions, it may still be developing some power. However, if the propeller is not feathered, and the power being delivered by the engine reduces to a level such that the propeller is windmilling rather than being driven by the engine, then the net effect on aircraft performance will be worse than if the engine is totally inoperative and the propeller is feathered.

1.20.3 Hierarchy of operational documentation

Two manuals provided information regarding the operation of the operator's C90 aircraft. These were, in order of precedence:

- the CASA *Approved Flight Manual*
- the operator's *Operations Manual.*

The CASA *Approved Flight Manual* for LQH consisted of the *FAA Approved Flight Manual*, which contained sections on operating limitations, normal procedures, emergency procedures, performance data and supplements. The aircraft manufacturer's *King Air C90 Pilot's Operating Manual* contained the *FAA Approved Flight Manual*. It also incorporated supplemental material such as additional performance data, detailed system descriptions, servicing instructions and safety information.

CAR 1988, r. 215, required an operator to provide an Operations Manual for the use and guidance of operations personnel. CAR 1988, r. 215(2) required the manual to contain 'information, procedures and instructions … to ensure the safe conduct of operations'.

Part A of the operator's *Operations Manual* stated that employee compliance with the manual was mandatory unless '… information or instructions in any aircraft Operating Manual overrides such advice.'

Part B of the operator's *Operations Manual* contained information and procedures relating to the operation of C90 aircraft. It stated that 'all operating limitations, conditions and requirements of the individual aircraft flight manual shall take precedence over any information contained in this part'.

The operator had three King Air C90 aircraft: VH-LQH (serial number LJ-644); VH-NQH (serial number LJ-655); and VH-SQH (serial number LJ-730). The *Approved Flight Manual* for LQH and NQH contained identical information. This manual differed from the *Approved Flight Manual* for SQH in terms of emergency procedures and critical take-off speeds (see Sections 1.20.5 and 1.20.8). Part B of the operator's *Operations Manual* was based on the *Approved Flight Manual* for VH-SQH.

1.20.4 Factors affecting flight with one engine inoperative

In the *Pilot's Operating Manual* for the C90 aircraft, the aircraft manufacturer published safety information relating to flight with one-engine inoperative. The manual stated that safe flight with one-engine inoperative required an understanding of the basic aerodynamics involved and proficiency in one-engine inoperative procedures. Loss of power from one engine affected both

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42 V_S may be defined as the minimum steady flight speed at which the aircraft is controllable (see Section 1.20.5).

climb performance and controllability of multi-engine aircraft. Climb performance required an excess of power over that required for level flight. The manufacturer's manual also stated that:

> Loss of power from one engine obviously represents a 50% loss of power, but in virtually all twin-engine airplanes, climb performance is reduced by at least 80%.

The amount of power required to climb depends on how much drag must be overcome. If drag is increased because the landing gear is extended, flaps are extended and/or the propeller is windmilling (not feathered), more power will be required to maintain performance. If the power available cannot be increased, then drag must be reduced in order for the aircraft to climb with one-engine inoperative. In addition to power and drag, one-engine inoperative climb performance also depends on airspeed and weight.[43]

Airspeed

In the *Pilot's Operating Manual,* the aircraft manufacturer stated that 'Airspeed is the key to safe single-engine operations.'

Drag increases as the square of the airspeed, while power required to maintain that speed increases as the cube of the airspeed. Therefore, any variation in airspeed above or below the nominated one-engine inoperative climb speed will result in a reduced climb performance in the event of an engine failure (see also Section 1.20.5).

Drag

An important consideration for multi-engine aircraft performance is to minimise aerodynamic drag in the event of an engine failure in flight. Drag can be caused by a windmilling propeller, extended landing gear and wing flaps, control surface deflection or aircraft attitude. In wings level one-engine inoperative flight, an aircraft will sideslip while maintaining heading, thus increasing drag. Banking up to 5 degrees toward the operating engine reduces drag, by reducing the sideslip, as well as the amount of rudder required to counteract yaw.

Drag from a windmilling propeller will cause an aircraft to yaw towards the failed or failing engine. Most multi-engine aircraft, including the C90, are equipped with full-feathering propellers. Full feathering results in the propeller blades being streamlined to the direction of aircraft travel and the propeller blade ceasing to rotate, which minimises drag and therefore the yawing tendency in the event of an engine failure. Examination of the wreckage indicated that the left propeller was not feathered at the point of impact. Propeller feathering is discussed in Section 1.6.5.

As stated in Section 1.12, examination of the wreckage revealed that the landing gear was locked in the extended position and the wing flaps were found to be retracted. Witness reports of aircraft attitude throughout the flight indicated that the aircraft was banking towards the left (or inoperative) engine.

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43 Information about one-engine inoperative operations was also provided in a number of articles published in the Aviation Safety Digest, a magazine issued to Australian pilots from 1953 to 1991. One of these articles is provided in Appendix E. The ATSB Air Safety Occurrence Report 200000492 (VH-NTL, Williamtown, 13 February 2000) also contains information about one-engine inoperative operations.

Power

One-engine inoperative climb performance requires the power available to be greater than the power required to overcome drag. Examination of the right engine and the propeller ground impact marks indicated that it was developing significant power at impact (see Sections 1.12 and 1.16). Examination of the left engine indicated that it was developing less than useful power at impact. Propeller drag increases significantly, adversely affecting one-engine inoperative performance, if the engine is at a low power level and the propeller is not feathered.

Weight

The take-off weight of an aircraft affects the power required to accelerate and climb. As stated at Section 1.6.7, the aircraft was loaded within allowable weight and centre-of-gravity limits.

1.20.5 Critical take-off speeds

A number of critical take-off speeds (known as V speeds) were relevant to the accident.

Air minimum control speed (V_{mca})

The aircraft manufacturer defined air minimum control speed (V_{mca}) as:

> …the minimum flight speed at which the airplane is directionally controllable… The airplane certification conditions include one engine becoming inoperative and windmilling, a 5-degree bank towards the operative engine, take-off power on operative engine, landing gear up, flaps in the take-off position, and most rearward C.G. [centre of gravity]

The aircraft manufacturer advised that '…most airplanes will not maintain level flight at speeds at or near V_{mca}'. The *Approved Flight Manual* specified a V_{mca} of 90 kts.

Stall speed (V_s)

The aircraft manufacturer defined stall[44] speed (V_s) as '… the minimum steady flight speed at which the airplane is controllable.'

The *Approved Flight Manual* included stall speed data for various weights, bank angles and configurations. No data was available for the stall speed for the configuration of the aircraft at the time of the accident, which was zero flap, landing gear down and a windmilling or unfeathered propeller. The aircraft manufacturer advised that performance data for that configuration was not available, but in general the aircraft reached V_{mca} before reaching the stall speed.

Rotation speed (V_r)

Rotation speed (V_r) was defined in the Part B of the operator's *Operations Manual* for the C90 aircraft as '…the speed at which the pilot rotates the aircraft for subsequent lift off.'

The manual specified a rotation speed of 90 kts at maximum take-off weight. Personnel responsible for the compilation of the manual reported that the 90 kts rotation speed was based on operator experience. The operator considered that 'to hold the aircraft on the ground would be pointless', and that by rotating the aircraft at 90 kts, the aircraft was able to accelerate in the air to achieve 100 kts by 50 feet above the runway. Several of the operator's pilots reported that they rotated the C90 aircraft at about 85 to 90 kts. The *Operations Manual* also included a take-

44 *Jane's Aerospace Dictionary*, 1988, describes a stall as a 'Gross change in fluid flow around [an] aerofoil … [at an angle of attack] just beyond [the] limit for attached flow, … characterised by [a] complete separation of [the] boundary layer from [the] upper surface and [a] large reduction in lift.'

off distance chart that gave a range of rotation speeds between 92 and 97 kts, depending on the aircraft's take-off weight. The take-off weight of LQH for the accident flight was about 4,170 kg, which corresponded to a specified rotation speed of 96 kts.

The investigation sought advice from the aircraft manufacturer regarding the recommended rotation speed. The manufacturer stated that '… the Take-Off Distance – 0% Flaps graph (Two Engines) specifies the take-off speed as being 100 knots'. The manufacturer did not define the term 'take-off speed'.

The FAA *Airplane Handbook* FAA-H-8083-3[45] stated 'the multiengine pilot's primary concern on all takeoffs is the attainment of [V_{mca}]… plus 5 knots prior to lift-off'. That is, for the C90 aircraft the preferred rotation speed would be at least 95 kts.

One-engine inoperative best angle-of-climb speed (V_{xse})

The aircraft manufacturer defined the one-engine inoperative best angle-of-climb speed (V_{xse}) as the 'airspeed that will give the steepest angle-of-climb with one engine out'. That is, V_{xse} is the speed which gives the greatest gain in altitude over the shortest possible distance. The *Approved Flight Manual* for LQH specified a V_{xse} of 96 kts.[46]

The aircraft manufacturer stated that 'V_{xse} is only used to clear obstructions during initial climb-out as it gives the greatest altitude gain per unit of horizontal distance. It requires more rudder control input than V_{yse}.'

Take-off safety speed (V_{toss})

Take-off safety speed (V_{toss}) may be defined as the speed selected to ensure that adequate aerodynamic control will exist under all conditions (including sudden, complete engine failure) during the climb after take-off. V_{toss} is never less than 1.1 V_{mca}, or 1.2 V_s.

The operator provided quick-reference performance information that was normally available to the pilot from a printed card carried aboard the aircraft. The card indicated that the V_{toss} was 101 kts for a take-off weight of 4,170 kg, which was the estimated take-off weight of LQH for the accident flight.

One-engine inoperative best rate-of-climb speed (V_{yse})

The aircraft manufacturer defined the one-engine inoperative best rate-of-climb speed (V_{yse}) as the airspeed which '… delivers the greatest gain in altitude in the shortest possible time …' with one engine inoperative.

The *Approved Flight Manual* for LQH specified a V_{yse} of 107 kts.[47] During a normal take-off with both engines operating, the aircraft would accelerate from V_{toss} to V_{yse} within a few seconds.

Most manufacturers of multi-engine aircraft below 5,700 kg MTOW recommended that, in the event of an engine failure during the initial climb, the nominated airspeed was V_{yse}, with V_{xse}

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45 Rewritten and revised in 1999, the US FAA *Airplane Handbook* FAA-H-8083-3 is the official FAA resource for pilot training (see Appendix F).

46 Part B of the operator's *Operations Manual* specified that V_{xse} was 101 kts (see Section 1.20.8). The *Approved Flight Manual* for SQH, a C90 aircraft with a later serial number to LQH (see Section 1.20.3) specified that V_{xse} was 100 kts.

47 V_{yse} varies with weight, being highest at the maximum take-off weight and lower for reduced weights. The *Approved Flight Manual* for LQH specified one value for V_{yse}, which was 107 kts and the value of V_{yse} for the accident flight was about this figure. Part B of the operator's *Operations Manual* specified that V_{yse} was 108 kts for King Air C90 aircraft. The *Operations Manual* was based on the *Approved Flight Manual* for SQH, which specified that V_{yse} was 107 kts. The reason for the discrepancy could not be determined.

only being required where necessary for obstacle clearance. This approach was also commonly advocated in general aviation flight training and flight safety publications (for example, see Appendixes E and F).

The *Approved Flight Manual* for LQH included emergency procedures to be used in the event of an engine failure during takeoff. The procedures stated that, if the aircraft was airborne and conditions precluded an immediate landing, the airspeed should initially be maintained at 'take-off speed' or above. The procedures specified that, after the landing gear was retracted and the propeller of the inoperative engine feathered, the aircraft was to be flown at the one-engine inoperative best rate-of-climb speed (V_{yse}).[48]

Decision speed or decision point

As discussed in Section 1.20.2, there was no requirement for most multi-engine aircraft below 5,700 kg maximum take-off weight (MTOW) to demonstrate a one-engine inoperative climb capability from takeoff. As a result, there was a need for pilots to follow procedures for managing an engine failure if it occurred late in the take-off roll, or prior to the nominated one-engine inoperative climb speed being achieved.

The aircraft manufacturer's *Pilot's Operating Manual* for LQH stated that the 'decision speed' was 100 kts.[49] The manufacturer specified the decision speed in relation to accelerate stop performance (see Section 1.20.6).The term 'decision speed' was not defined in the manual. However, the term is generally regarded as being the speed at or above which, should an engine fail, the takeoff would be continued.[50]

Some operators of this category of aircraft use a decision point rather than a decision speed. A decision point is usually a combination of speed with one or more additional parameters such as a height above ground level, a positive rate of climb and/or a configuration (for example, gear retracted). Given the limitations of one-engine inoperative climb performance, it is a commonly recommended practice that the speed parameter of the decision point should be at or above V_{yse}.[51] Depending on the operator's procedures, the decision point for a particular flight may vary depending on ambient conditions, runway characteristics, surrounding terrain and aircraft weight. For example, during a takeoff on a long runway the decision point may occur further along the aircraft flight path relative to a takeoff on a shorter runway.

Figure 17 shows the relationship between liftoff, a 'reject take off area', a decision point and a 'continue takeoff area'. The 'reject takeoff area' is where the aircraft may not perform adequately on one engine, even if it is correctly configured. After the decision point, in the 'continue takeoff area', the aircraft will probably be able to perform adequately on one engine when correctly configured, Depending on the subsequent aircraft performance, the pilot may need to reassess the decision to continue the takeoff with one-engine inoperative. Figure 17 shows the decision point as occurring at V_{yse} and the landing gear retracted or in transit to the retracted position; this is illustrating a commonly recommended practice and may not be appropriate for all situations.

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48 The *Approved Flight Manual* for SQH also specified V_{yse}, after obstacle clearance altitude was reached, in the emergency procedures. The operator's *Operations Manual* had essentially the same procedures (see Section 1.20.8).

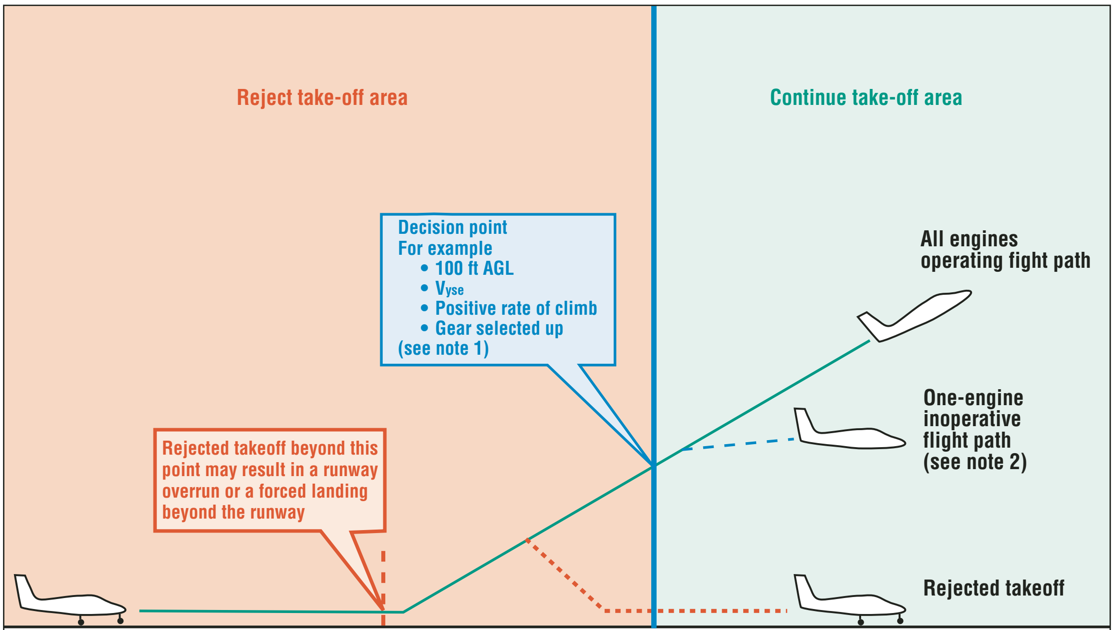
49 The *Approved Flight Manual* for SQH stated that the decision speed varied from 92 to 97 kts, depending on aircraft weight. These speeds were the same as the specified rotation speed.

50 It is important to note that the term 'takeoff' refers to the ground roll and initial climb phases of flight.

51 For example: (1) FAA, *Flying light twins safely*, FAA Aviation Safety Program Publication, FAA-P-8740-66, 2001. (2) New Zealand Civil Aviation Authority, 'Flying light twins safely', *Vector*, July/August 1999. (3) J. C. Eckalbar, *Flying high performance singles and twins*, Skyroad Projects, Chico, California, 1994.

There was no requirement for a decision speed or a decision point to be specified in Australia for most multi-engine aircraft below 5,700 kg MTOW, including the C90.[52] The operator's procedures for responding to an engine failure are discussed in Section 1.20.8.2.

FIGURE 17:
Take-off performance aspects of multi-engine aircraft below 5,700 kg MTOW



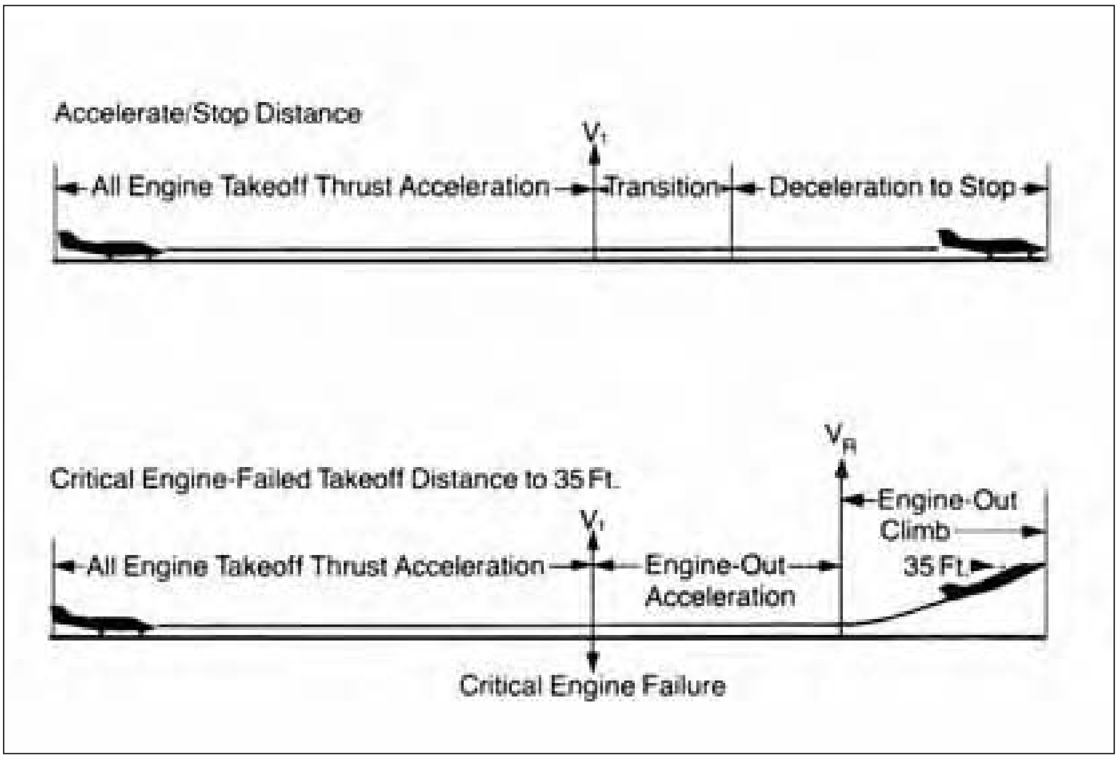
Notes:
1. Decision point may vary due to local conditions. For example,if obstacle clearance is a consideration immediately after takeoff, then the appropriate speed would be V_{xse} until obstacle clearance altitude is reached.
2. Decision to continue flight will need to be reassessed depending on adequate aircraft performance.

There is a difference in the required performance capability of transport category aircraft above 5,700 kg MTOW and aircraft with a MTOW below 5,700 kg used in general aviation operations. Large transport category aircraft are required to be capable of safely rejecting a takeoff at or below a specified decision speed (V_1), or safely continuing a takeoff above this decision speed, following the failure of an engine (see Figure 18).[53]

52 A take-off decision speed, termed V_1, was required for transport aircraft with a MTOW above 5,700 kg.

53 The MTOW of 5,700 kg was an arbitrary barrier that separated small aircraft from the large transport category type of aircraft. LQH had a maximum take-off weight of 4,377 kg.

FIGURE 18:
Take-off performance requirements for transport aircraft above 5,700 kg MTOW



1.20.6 Take-off performance for the accident flight

All engines take-off performance

The *Approved Flight Manual* for LQH included a take-off distance chart. The chart indicated that with both engines operating, and a take-off weight of 4,170 kg, the aircraft would have a ground roll of about 560 m and a take-off distance of about 685 m. However, the data in that chart was unfactored. Applying the 1.25 factor specified in CAO 20.7.4[54], the take-off distance required was 856 m. Runway 29 at Toowoomba was 1,121 m long.

The aircraft manufacturer did not provide any data on the effect of runway slope on take-off distance. CASA draft advisory circular AC 91-225(0), *Safety During Take-off and Landing for Small Aeroplanes*, advised that the take-off distance would increase by 10 per cent for a 2 per cent runway up-slope. The investigation estimated that the effect of the slope of runway 29 at Toowoomba would have added about 30 m to the ground roll.

54 CAO 20.7.4 subsection 6.1 specified that the take-off distance required is the distance to accelerate from a standing start with all engines operating and to achieve the take-off safety speed at a height of 50 ft above the take-off surface, multiplied by a factor of 1.25 for aircraft with a maximum take-off weights of 3,500 kg or greater.

Accelerate-stop performance

The aircraft manufacturer defined accelerate-stop distance as the '… distance required to accelerate an aircraft to a specified speed and, assuming failure of an engine at the instant that speed is attained, to bring the airplane to a stop.' There was no requirement in CAO 20.7.4 for accelerate-stop distance to be considered for operation of aircraft such as the C90.

The aircraft manufacturer had published, in the *Pilot's Operating Manual*, a performance chart from which accelerate-stop distance for the C90 could be determined. The chart included an allowance of 3 seconds for the pilot to recognise an engine failure. The data was based on take-off power being set before brakes release and both engines being at idle power at the 'decision speed' of 100 kts. The distance was calculated using a paved, level and dry runway surface, and did not take account of the use of 'propeller reversing'.[55] Runway 29 at Toowoomba and the area beyond the end of the runway were not level. The aircraft manufacturer advised that, under the circumstances prevailing at the time of the accident, the accelerate-stop distance was about 1,300 m. The length of runway 29 was 1,121 m, which was the accelerate-stop distance available published in *En-route Supplement Australia*. Therefore, the accelerate-stop distance, for the C90 aircraft, extended beyond the end of runway 29 at Toowoomba.

One-engine inoperative take-off performance

The *Pilot's Operating Manual* contained information regarding one-engine inoperative take-off performance, including a chart from which 'Single-Engine Take-off Distance - 0% Flaps' could be derived. The aircraft manufacturer advised that the aircraft would have had a ground roll of about 590 m, and a take-off distance of about 1,105 m, if an engine failed at liftoff with a 'take-off speed' of 100 kts. That calculation was predicated on the take-off power being set before brake release, the flaps up and landing gear being retracted after lift off, and the runway being a paved, level, dry surface.

The chart included a note, which stated that:

> DISTANCES ASSUME AN ENGINE FAILURE AT LIFT OFF AND PROPELLER IMMEDIATELY FEATHERED.

Examination of LQH indicated that the landing gear was not retracted and the left engine propeller was not feathered at impact. Additionally, runway 29 was not level.

One-engine inoperative climb performance

The *Approved Flight Manual* indicated that at a V_{yse} of 107 kts, LQH should have been capable of climbing at a rate of about 430 ft/min with the flaps up, the landing gear retracted, the inoperative engine's propeller feathered and maximum continuous power on the operative engine. The one-engine inoperative rate-of-climb is highly dependent on airspeed and if the optimum airspeed (V_{yse}) is not reached, the aircraft may not achieve the published climb performance, even if it is appropriately configured. The *Approved Flight Manual* only provided one-engine inoperative climb performance data at 107 kts. Obstacle clearance was not a consideration for the accident flight.

1.20.7 Pilot response and performance

Response time refers to the time from the onset of a stimulus until the time that a person makes a response. Response times in applied settings, such as responding to an engine failure during

[55] Propeller reversing is a ground-only setting in which propeller blades reverse the normal direction of thrust.

the take-off roll, can vary due to a number of different factors. Available research suggests that, in situations where the failure occurs close to the point at which pilots have to decide whether to reject the takeoff or continue the flight, the average pilot response time will be at least 2 seconds. Further information regarding the factors that can influence pilot response time and relevant research is presented in Appendix G.

In order to minimise the response times and ensure the most appropriate decisions in the event of an emergency, it is an industry practice that pilots conduct a pre-takeoff briefing. This briefing includes mentally reviewing the emergency procedures and deciding on the conditions of airspeed, height, rate of climb and/or aircraft configuration that must exist in order to continue the flight in the event of an engine failure. The pilot should endeavour to be mentally prepared to act, so that if an engine failure occurs before these conditions are met, the power levers are retarded and a controlled landing on the most suitable area ahead is conducted.

A number of previous accidents both in Australia and overseas have involved undesirable pilot responses to engine failures during takeoff (see Appendix H).

1.20.8 Procedures for engine failure during takeoff

Aircraft manufacturer's procedures

The aircraft manufacturer specified the emergency procedures for the C90 aircraft in the *Approved Flight Manual*. The procedures for responding to an engine failure during takeoff are shown in Appendix I. Salient aspects of these procedures were:

- If the aircraft was below the manufacturer's specified 'take-off speed' (100 kts, see Section 1.20.5), then the takeoff was to be rejected.
- If the aircraft was airborne and 'conditions preclude an immediate landing', then the aircraft was to be flown at the manufacturer's specified 'take-off speed' or above until it was configured for one-engine inoperative flight. After the aircraft was appropriately configured, the aircraft was to be flown at V_{yse}.

Operator's procedures

Part A of the operator's *Operations Manual* contained a section titled 'Emergency and Non-normal Procedures'. This section did not refer to a particular aircraft type and was directed primarily at two-pilot operations. However, the following extracts were relevant:

> It is impossible to list all the factors that could lead to the decision to discontinue a take-off…
>
> An engine failure must be indicated by two or more instruments (Torque and temperature)…
>
> Careful and deliberate action is required in identifying and shutting down a malfunctioning engine. Avoid hasty action and initiate a shut-down only after the engine is positively identified and identification is confirmed.

Part B of the manual stated that the philosophy behind the manual took into consideration two distinct cases: emergencies below V_1 and emergencies above V_1. V_1 was defined as:

> *Take-off Decision Speed*. The speed at which the pilot will continue the take off should there be loss of power to one engine.

The operator reported that pilots were responsible for nominating a decision speed prior to takeoff. The *Operations Manual* did not specify a decision speed for the C90, or factors to consider when nominating a decision speed.

The operator's quick-reference performance card, carried aboard the aircraft, included the note "… MANUFACTURER RECOMMENDED VDEC 100 KTS'. This note was not included in Part B of the operator's *Operations Manual* containing procedures relating to the C90 aircraft.[56]

During the investigation, one of the operator's pilots reported that if the failure occurred below 85 kts, there was no option but to reject the takeoff. If the failure occurred after 90 kts the aircraft would be airborne, and the safest course of action at Toowoomba was to fly straight ahead. Another of the operator's pilots reported that he used a decision speed of 103 kts. Another pilot reported that, in his experience, the decision point on a long runway would be after the landing gear was selected UP, whereas the decision point for short runways was at rotation. The decision speed or decision point normally used by the pilot of the accident flight could not be determined.

Section 3.2 of the *Operations Manual* contained the emergency checklists for the C90 aircraft. A copy of the operator's procedures for responding to an engine failure is shown in Appendix J. Salient aspects of these procedures were:

- If the aircraft was still on the runway, then the takeoff was to be rejected.
- If the aircraft was airborne and 'conditions preclude an immediate landing', then the aircraft was to be flown at the 'take-off speed' or above until it was configured for one-engine inoperative flight. After the aircraft was appropriately configured, and obstacle clearance altitude was reached, the aircraft was to be flown at V_{yse}. The 'take-off speed' was not defined in the operator's manual.

These aspects of the procedures were the same as those specified in the *Approved Flight Manual* for SQH.

Section 4.2.1.9 of Part B of the operator's *Operations Manual* stated that a take-off briefing was required, and that it should include the 'salient speeds to be used during take-off' and 'emergency actions during take off and initial climb'.

The manual did not contain information regarding considerations or options for pilots when operating C90 aircraft at locations where unique features were present, such as at Toowoomba aerodrome.

1.20.9 Engine failure training and testing

To develop and maintain skills in handling engine failure emergencies, pilots need continual practice and review. For general aviation pilots, the opportunity to practice engine failure emergencies may be limited to flight tests. Due to the circumstances of flight testing, there are a number of factors that may make the multi-engine flight test less representative of an actual engine or system failure, and therefore limit the type of failures that can be simulated. These factors include:

- The aircraft is usually flown at a relatively low weight.
- Most practice engine failure exercises are conducted either below 40 kts or above V_{yse}.

56 The term 'VDEC' was not defined in the operator's *Operations Manual*. However, from its use in Part A of the manual, the term appeared to refer to a decision speed to be used in the event of an engine failure.

- In a training or testing situation, the pilot has the advantage of knowing that a failure is probably about to be simulated and that the simulation will occur at a height and speed that would allow the aircraft to safely climb away with one-engine inoperative.
- A number of simulated emergency training sequences, such as simulated engine failures during takeoff at speeds at or near to V_r involve high risk.[57]

The Civil Aviation Advisory Publication (CAAP) 5.23-1 (0) *Syllabus of training – Initial issue of a multi-engine aeroplane type endorsement (rating)* was issued in September 1996. The document contained information regarding the course of ground and flight training which candidates seeking their first multi-engine endorsement should undertake. The syllabus was also applicable to subsequent endorsements.

The CAAP 5.23-1 (0) stated that candidates for other than initial multi-engine type endorsements were not required to complete the syllabus as specified, however all applicable items on the endorsement application form should be satisfactorily completed. The document did not provide guidance information regarding decision making for engine failures between 40 kts and V_{yse}. Seven hours flight training was recommended for an initial multi-engine type endorsement. The pilot in command of LQH was an experienced multi-engine pilot. He received 6.3 hours of endorsement training on the C90, which included one-engine inoperative procedures. The training was carried out by a CASA-approved Authorised Testing Officer employed by the operator.

The investigation team discussed multi-engine training with a number of operators and check and training pilots. Opinions amongst the pilots and operators varied widely regarding the considerations and procedures to be taken in the event of an engine failure during takeoff in multi-engine aircraft below 5,700 kg MTOW, including decision speeds or decision points at which to reject or continue the takeoff.

The pilot's C90 endorsement training was conducted in accordance with Part C of the operator's *Operations Manual*, titled the *Check and Training Manual.* The manual specified a course of training that included the procedures to follow in the event of an engine failure both before and after take-off and flight at V_{mca}. CAAP 5.23-1 and the operator's *Check and Training Manual* did not specifically address the situation of an engine failure occurring during the critical period between liftoff and prior to V_{yse}, when the safest course of action may be to carry out a controlled descent to a landing in unfavourable terrain. The manual contained information dealing with the situation of an engine failure occurring during the critical period immediately before rotation.

The *Check and Training Manual* also stated that all company pilots would be checked in accordance with the CAR 1988 r. 217, which required two base checks per calendar year, not closer than 4 months apart. The manual specified that a base check was to include a rejected takeoff, an engine failure during takeoff, and an engine out circuit approach, landing and overshoot. The manual also stated that the engine failure on takeoff should be introduced 5 to 10 kts after V_{toss} had been reached.

The operator reported that it conducted simulated engine failure practice no lower than 300 ft above ground level during its training activities. It also reported that it conducted rejected take-off practise, but at speeds well below rotation speed. The operator considered that practice of the technique was more important than the actual speed at which it was conducted. This

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57 For example, refer to the then Bureau of Air Safety Investigation (BASI) report 199503057 (Fairchild SA227, VH-NEJ, Tamworth, 16 September 1995) and the ATSB Air Safety Occurrence Report 200000492 (Beech 1900D, VH-NTL, Williamtown, 13 February 2000).

training approach appeared to be consistent with that used by other operators of multi-engine aircraft below 5,700 kg MTOW. The operator reported that it did not conduct rejected take-off practise at Toowoomba due to the length of the runway.

CAO Part 40 section 40.2.1 Appendix 1 (CMEIR test) stated that:

> …failure of the engine shall be simulated at a speed greater than either the one engine inoperative best rate of climb speed or take-off safety speed plus 10 kts, whichever is the higher.

In the case of the C90, that speed was approximately 117 kts. There was also no requirement to test rejected takeoffs during a CMEIR renewal.

As noted in Section 1.5, the pilot completed a base check and CMEIR flight test on 20 February 2001. Another base check was therefore due before 31 December 2001. The pilot's most recent opportunity to practice a simulated engine failure was during a flight test for the issue of a US Air Transport Pilot licence on 7 May 2001. The investigation was unable to confirm if a simulated engine failure was conducted during the test.

1.20.10 Synthetic flight trainers

Certain simulated aircraft emergencies, including simulated engine failures during critical phases of flight, involve high risk. The use of synthetic flight trainers enable these simulated emergencies to be conducted without compromising the safety of flight. CAO Section 40, *Pilot Licences and Ratings* included provision for the use of synthetic flight trainers.

Large air transport organisations are able to utilise high fidelity flight simulators to conduct a number of pilot training programs, such as type conversions and recurrent and emergency training involving simulated emergencies, which may not be possible to conduct in an actual aircraft.

There were a number of synthetic flight trainers in use in flying training organisations in Australia that were configured to represent a generic multi-engine aircraft below 5,700 kg MTOW. At the time of this accident, they did not incorporate full-motion and/or high quality visual displays. However, most incorporated a complete cockpit and instrument display that allowed instrument flying practice with limited fidelity. High fidelity flight simulators for multi-engine aircraft below 5,700 kg MTOW were not available in Australia.

During the investigation, CASA advised the following:

> There are no flight simulators for this class of aeroplane in Australia and therefore no accreditation available for any aircraft handling or instrument flight. There are a number of synthetic flight trainers that resemble the cockpit instrument layout of a B200 or C90 aeroplane but their accreditation is limited to specific instrument flight sequences. There is no accreditation for aircraft type handling particularly in asymmetric sequences. The majority of these synthetic trainers have a very limited visual display of conditions outside the aircraft typically on a single cathode ray tube with forward vision of +/- 30 degrees of aircraft heading at the best and extremely limited vertical up/down display.

CAO 82.3, *Conditions on Air Operator's Certificates Authorising Regular Public Transport Operations in other than High Capacity Aircraft* stated that an operator may use flight simulators/synthetic trainers for training and testing purposes.

Most operators of multi-engine aircraft below 5,700 kg MTOW in Australia, including the operator of LQH, did not use synthetic trainers for practising emergency procedures. The low usage of these devices was probably due to their limited value for practicing aircraft handling in an emergency. However, synthetic flight trainers currently available in Australia could be used for safely practicing the decision-making skill of determining whether to reject or continue with a takeoff, given an engine failure or other emergency at a particular point during the takeoff.

1.20.11 Guidance for pilots regarding engine failures during take-off

The aircraft manufacturer included information regarding flight with one-engine inoperative in the *Pilot's Operating Manuals* for its aircraft. A number of international aviation regulatory authorities have also produced guidance material regarding flight with one-engine inoperative.[58]

CASA did not publish any formal guidance material for pilots and operators about managing an engine failure during takeoff in multi-engine aircraft. However, CASA did periodically publish articles in flight safety publications such as *Flight Safety Australia*.[59] A copy of one such article is included in Appendix K.

58 For example: (1) FAA *Airplane Handbook* FAA-H-8083-3, Chapter 14, *Transition to a multiengine airplane* (see Appendix F). (2) FAA, *Flying light twins safely*, FAA Aviation Safety Program Publication, FAA-P-8740-66, 2001. (3) New Zealand Civil Aviation Authority, 'Flying light twins safely', *Vector*, July/August 1999. (4) UK Civil Aviation Authority, *General Aviation Safety Sense Leaflet 7B, Aeroplane Performance*.

59 *Flight Safety Australia* magazine is published by CASA and distributed to aviation licence holders in Australia.

2 ANALYSIS

2.1 Introduction

The central event in this accident was the failure of the left engine, which was the critical engine on the aircraft in terms of aircraft performance considerations. The available witness evidence suggests that this failure occurred just prior to, or at about the time the aircraft became airborne (see Section 2.4.1). Following the engine failure, the pilot elected to continue with the takeoff. Control of the aircraft was lost, and the subsequent impact and post-impact fire were not considered survivable.

In common with most transport accidents, this occurrence involved a number of different contributing factors. Although some of these factors were associated with actions of individuals or organisations, it is essential to note that the key objective of a safety investigation is to identify safety deficiencies or weaknesses in the safety system and to learn how to minimise the risk of future accidents. It is not the purpose or intention of the investigation to apportion blame, or to provide a means of determining liability.

This analysis initially focuses on the circumstances surrounding the failure of the left engine. There was evidence in the ECTM data that a potentially safety-critical problem existed in the engine for several weeks prior to the accident. For a variety of reasons, the evidence was not detected and analysed, nor was appropriate remedial action initiated. Without timely intervention to address the developing engine problem, it was increasingly probable that the aircraft would have an in-flight emergency involving the left engine.

The analysis then discusses the circumstances surrounding the pilot's response to the engine failure. An engine failure or malfunction in a multi-engine aircraft should not necessarily result in an accident. However, in this case, the failure occurred during a critical phase of flight, in a situation that was among the most difficult for a pilot to respond to in a manner that would ensure a safe outcome. Nevertheless, the likelihood that the pilot would respond more effectively to the situation could have been improved with more robust defences.

2.2 Maintenance-related events and conditions

2.2.1 Left engine failure

The damage to the left engine was consistent with the fracture and release of one or more compressor turbine blades into the engine gas path. This would have initiated the release of other compressor turbine blades, and their subsequent impact with the adjacent and downstream components. It was evident, from the nature of the damage, that the engine was not producing useful power at impact. Given the extent of the damage to the engine, the loss of useful power probably occurred almost immediately after the blade failure.

The evidence indicated that the left propeller was not feathered at impact. There were several possible reasons to explain why the propeller was not feathered. These included:

- The automatic propeller feathering system may not have been armed. However, it was normal operating procedure for the automatic propeller feathering system to be armed for takeoff, and there was no evidence to suggest that the system was not armed on this occasion.

- The automatic propeller feathering system may have had a technical malfunction. However, there was no evidence to suggest that the auto-feather system for the left engine had a pre-existing fault or that a failure occurred on the accident flight.
- It is possible that the compressor turbine section of the engine was still rotating and producing a degree of power throughout the short duration of the flight, even though the evidence indicated that the engine lost all useful power almost immediately after the initial compressor turbine blade failure. If the power loss was such that the engine torque only fell below 160-240 foot pounds within 7 seconds prior to impact, then the auto-feathering process would not have been completed. There was no evidence from the examination of the engine and propeller to confirm whether this scenario occurred.
- The pilot may have retarded the left engine power lever in response to the engine failure; an action that would have disarmed the automatic propeller feathering system if the power lever was retarded below the 90 per cent N1 position. There was no evidence to confirm whether this scenario occurred (see also Section 2.4.2).

The examination of the left engine by the Canadian TSB found that it failed as a result of the conditions under which it was operated rather than as the result of any manufacturing defect. Detailed examination of the compressor turbine blades revealed no evidence of time dependent material failure such as fatigue or creep. There was no evidence that the engine failure was related to a birdstrike or other foreign object impact just prior to the failure, or that the failure was related to the quality or quantity of the fuel on board the aircraft.

The TSB found that the compressor turbine blades had been exposed to higher than normal operating temperatures. The exposure to higher than normal temperatures probably weakened the structure of the blades. As would be expected under such conditions, the blade failure occurred at high engine power, when operating stresses within the engine were at their greatest.

The TSB report did not discuss the reason the compressor turbine blades were exposed to higher than normal operating temperatures. However, it noted that the ECTM data for the left engine showed a 20-degree rise in the delta inter-turbine temperature (ITT) trend line over the months preceding the accident (see Appendix B). The investigation's examination of the trend data for the left engine showed a gradual increase in delta ITT between when the baseline took effect (4 July 2001) and 21 November 2001. The delta ITT had reached a level of 20 degrees above baseline by the end of October. The change in delta ITT had occurred in about 129 hours of operation, which indicated that a serious problem had developed. The increase in delta ITT was accompanied by a slight increase in fuel flow (Wf) and a gradual increase in compressor speed (Ng) of nearly 1 per cent over the same period. According to the engine manufacturer's guidance material, this pattern of results was consistent with a problem with the efficiency of the cold section of the engine. A decrease in cold section efficiency would have meant that, to achieve target torque during takeoff, a higher than normal fuel flow into the engine was required. A higher fuel flow would have resulted in higher than normal ITT.

An alternative explanation for the higher than normal operating temperature is that the left engine had been subjected to an over-temperature condition during an engine start, known as a 'hot start'. However, there was no evidence recorded in the aircraft's maintenance documentation that such an event occurred. The pattern of ECTM data was also not consistent with the typical pattern expected of a hot start.

The exact reason why there was a decrease in the efficiency of the cold section of the engine could not be determined due to the nature and extent of the impact and post-impact fire damage to the engine. Possibilities included a dirty compressor, foreign object damage to the compressor, or air leaks.

In summary, the evidence from the examination of the engines indicates that the left engine failed after a blade was released from the compressor turbine, and the compressor turbine blades had previously been exposed to above normal operating temperatures. The evidence from the ECTM data indicated that there was a significant problem developing in the cold section of the engine over an extended period, which led to an increase in the operating temperature within the engine. This pattern of evidence suggested that a problem with the efficiency of the cold section of the engine probably led to temperature-related damage to the compressor turbine blades, which probably resulted in the failure of one of those blades. However, some other explanations for the failure, such as a hot start leading to or exacerbating the temperature-related damage, could not be discounted.

The ECTM data for the right engine indicated that a potential problem was also developing in the cold section of that engine for a period of time. However, the extent of the increase in the delta ITT and delta Ng at the time of the accident was not of the same magnitude as that for the left engine.

2.2.2 Recording and analysis of ECTM data

The data required for ECTM was not being recorded by the operator's pilots as frequently as required by the manufacturer's guidelines or by CASA's requirements under AAC 6-29, and therefore AD/ENG/5. Ultimately, this was not a factor in the accident, as there was sufficient data available from what was recorded to detect the trend changes.

In terms of the analysis of the ECTM data, the operator did not have the expertise to analyse the data after early August 2001, when the previous maintenance controller resigned. The operator subsequently arranged to send the data to the engine manufacturer's field representative on a fortnightly basis for analysis, although AAC 6-29 required the data to be analysed twice a week. Based on the documentary evidence available, the investigation considered that it was unlikely that the field representative received any data on LQH's engines for flights after 12 September 2001.

The *PT6A Maintenance Manual* recommended that a performance recovery wash be conducted if the delta ITT trend line reached 10 degrees above baseline, and further maintenance action be conducted if the trend line reached 15 degrees above baseline. A 10-degrees increase would have been evident in early September 2001. The field representative had access to the data for flights up to the 12 September 2001.

The reason the field representative did not alert the operator to the increase in the delta ITT trend line above that required for remedial action could not be determined. Given his significant experience in analysing ECTM data, it seems unlikely that he would have analysed the data and not detected the developing problem. Regardless of why the field representative did not detect the developing problem in the data up to 12 September 2001, the fact remains that he was not provided with any additional data after that time. By not submitting the data to the field representative on a regular basis, the operator lost the chance to detect the rise in delta ITT beyond 10 degrees.

The investigation could not ascertain the exact reason(s) the chief engineer did not submit the ECTM data to the field representative on a more regular basis. There was evidence that the chief engineer was experiencing a high workload during this period, based on his own reports and also the level of maintenance resources available (see Section 2.3.1). It is possible that this workload contributed to the omission. In addition, prior to the accident, the chief engineer had not attended a training course on ECTM. He consequently had a low level of knowledge about the subject, and may therefore not have fully appreciated the importance of regular and reliable recording and analysis of ECTM data.

2.2.3 Maintenance of the left engine

Using the provisions of AD/ENG/5, the operator had elected to extend the time between overhaul (TBO) interval of its PT6A engines to 5,000 hours, which exceeded the 3,600 hours specified in the engine manufacturer's service bulletins. The time since overhaul for the left engine when the accident occurred was 3,556.0 hours. Therefore, the increased TBO allowed by the AD did not directly contribute to the accident.

The last work on the aircraft's engines, as recorded in the aircraft maintenance certification log, was conducted on 7 June 2001. The AD/ENG/5 required that a compressor performance recovery wash in response to trend monitoring parameter deviations, or at intervals not to exceed 3 months or 220 hours, whichever came first. The *PT6A Maintenance Manual* also stated that a performance recovery wash was required if the delta ITT reached 10 degrees above baseline, and this would have been apparent for the left engine in early September 2001.

The operator's 'maintenance notification' spreadsheet contained an entry to indicate that a compressor recovery wash had been conducted on one or both of LQH's engines on 27 September 2001. However, there was no evidence that any such action had been conducted or certified in the aircraft maintenance certification log. The spreadsheet also indicated that the last performance recovery wash had been conducted on one or both of the engines at 6,772.2 hours, which occurred on 7 June 2001.

The investigation noted that the ECTM data for the left engine showed a decrease in the delta ITT and delta Ng trend lines at about or just after 27 September, followed by an increase in both parameters. A similar pattern occurred for the right engine. It could be argued that this data pattern was consistent with a compressor wash being conducted on both engines on 27 September. However, the decrease in the deltas at this point could have been part of normal variation in the recorded data. More importantly, the low delta ITT and Ng values recorded on 1 October would have contributed to the overall decrease in delta ITT and Ng trends. The low values for both engines on this date suggest that there may have been an error in recording indicated airspeed, altitude or outside air temperature.

Based on the available evidence, the investigation concluded that a performance recovery wash had most probably not been conducted on the aircraft's engines since 7 June 2001, over 5 months prior to the accident. The entry in the maintenance notification spreadsheet on 27 September 2001 was probably an inadvertent data entry error.

Had the performance recovery wash been conducted on the left engine at the appropriate time, it may have been effective in removing the source of the deterioration in cold section efficiency. Alternatively, the wash and the associated power assurance run may have highlighted that further investigation was necessary to identify the source of the problem.

The investigation could not determine why a performance recovery wash was not performed on the aircraft's engines for over 5 months prior to the accident. However, the investigation noted that there were inconsistencies in the data entered in the maintenance notification spreadsheet relating to performance recovery wash requirements for both engines. These inconsistencies may explain why the chief engineer (as maintenance controller) did not detect that the performance recovery wash for both engines on LQH were overdue. The chief engineer's workload may also have contributed to the omission.

The investigation could not determine whether new blades had been installed on the compressor turbine of the left engine at its last overhaul at 3,275 engine hours. If new blades had not been installed at that time, then the blades would have required another inspection by 3,000 hours after the overhaul. There was no record found of such an inspection. However, as there was no evidence found of any manufacturing defect, fatigue or creep in the blades, it is unlikely that this possible omission had any bearing on the accident.

2.3 Maintenance-related defences and organisational conditions

2.3.1 The operator's maintenance resources

As noted in Sections 2.2.2 and 2.2.3, the chief engineer's workload may have contributed to omissions in maintenance scheduling and the sending of ECTM data for analysis. The chief engineer's workload appeared to be a direct result of the level of maintenance resources available and the number of roles he was performing at the time. The investigation estimated that, when the operator started conducting the maintenance for its fleet of aircraft, approximately three maintenance personnel were needed to conduct the required maintenance tasks. In addition to the chief engineer, there was an AME and an apprentice, who together would have been equivalent to about 1.25 maintenance personnel. The operator reported that it had access to additional maintenance personnel on an as needed basis. However, the operator's maintenance worksheets indicated that the level of usage of the additional maintenance resources was minimal prior to the accident.

The chief engineer's workload would have been exacerbated by the need for him to supervise the activities of the AME and the apprentice, as he was the only LAME in the organisation. He was also required to supervise the activities of contract maintenance personnel.

The chief engineer's workload would have significantly increased when he took on the additional role of maintenance controller for the operator on 3 August 2001. This role was previously performed as a full-time position by another employee. The chief engineer reported that this increase in workload was offset by a decrease in flying activity. However, the available evidence suggests that there was only a small decrease in the operator's flight hours after he became the maintenance controller in August 2001.

The extent to which the operator's management was aware of the chief engineer's workload, or had the financial resources to address the situation, was not determined.

2.3.2 The operator's other maintenance-related defences

In addition to the level of maintenance resources, the investigation noted that the defences within the operator's maintenance organisation were also deficient in a number of other areas.

The chief engineer had minimal preparation for his role as maintenance controller. Although he had worked in supervisory roles in the military, he had not worked in a similar role for a civil operator where the maintenance documentation and work environment were markedly different. Even though he had successfully completed an interview and a written exam with CASA to be approved in the position, he still had to become familiar with a range of requirements in airworthiness directives, service bulletins, and similar documents for several different aircraft and engine types. Given his high workload as manager and the only LAME, it would have taken significant time for him to become aware of all the requirements that impacted on maintenance scheduling for the operator's fleet of aircraft. These difficulties would have been exacerbated by the brief handover period from the previous maintenance controller, and the lack of any formal training for the role.

In addition, there were deficiencies in the arrangement to conduct ECTM analysis. Proper management and analysis of ECTM data was a critical part of the engine maintenance system, and ultimately, engine reliability assurance. However, the arrangement between the operator and the field representative regarding the analysis of ECTM data was informal, and there were no mechanisms in place to ensure that the data was sent to the field representative on a regular basis. The arrangement also did not comply with the requirements of AAC 6-29, and therefore AD/ENG/5, as it was agreed that the data would only be sent every 2 weeks. In addition, the person entering the data (the chief engineer) had not received ECTM training. Until the chief engineer received the required training to conduct ECTM, the operator could have entered into a formal arrangement with an appropriately qualified person. Such services could also have been purchased from a number of consultancy organisations.

There were also deficiencies in the maintenance scheduling processes used by the operator. Before an aircraft maintenance release is issued, all scheduled maintenance that falls due in the period of the validity is required to be entered on the maintenance release. The performance recovery wash requirements were not entered on three previous maintenance releases issued for LQH. This did not include the maintenance release valid at the time of the accident as it was not available. If that information had been entered, it may have provided a salient reminder to the operator's pilots and the chief engineer that a performance recovery wash was required.

The design of the operator's computer-based maintenance notification spreadsheet also had limitations. The absence of an automatic alerting feature significantly reduced the effectiveness of the spreadsheet to notify the chief engineer of scheduled maintenance requirements. As discussed in Section 2.2.3, an erroneous entry in the spreadsheet may have reduced the ability of the chief engineer to detect that a performance recovery wash was overdue for both engines of LQH. The computer-based aircraft maintenance certification log could have been developed so that, when the completed maintenance actions for scheduled tasks were entered into the log for a given date, the maintenance notification spreadsheet was automatically updated. If the two spreadsheets had been linked in this manner, the likelihood of a data entry error affecting the next due date may have been reduced.

2.3.3 CASA's introduction of AD/ENG/5

AD/ENG/5 allowed operators to elect to extend the time between overhaul (TBO) of their engines from 3,600 hours to 5,000 hours, provided certain maintenance actions were conducted. CASA relied on its surveillance processes to confirm compliance with these requirements (see Section 2.3.4). By comparison, the engine manufacturer specified an incremental extension of an operator's fleet of engines by only 500 hours at a time, and only if a sample engine from the fleet was overhauled and inspected and found to be satisfactory. Therefore, the manufacturer's process for allowing a TBO extension also had a built-in and ongoing method of confirming that appropriate maintenance processes were being conducted by the operator.

In summary, the introduction of AD/ENG/5 allowed life extensions to be approved for PT6A engines under less restrictive circumstances compared with those required by the engine manufacturer. The primary purpose for allowing a wider range of operators to increase TBOs was based on economic considerations for small operators, rather than to correct an unsafe condition.

CASA had introduced mitigators to offset the increase in TBO. For example, CASA mandated that operators who were extending the TBO to 5,000 hours had to conduct certain maintenance actions. However, most of these actions were effectively addressed under the engine manufacturer's requirements. The primary difference between the two sets of requirements was that the AD mandated the use of ECTM in order to obtain the TBO extension to 5,000 hours. The engine manufacturer encouraged operators to use ECTM, but did not specifically require ECTM in order to incrementally extend fleet TBOs.

The AD required compliance with the manufacturer's *ECTM User's Guide & Reference Manual*, but did not specify compliance with the manufacturer's maintenance manuals. There was an inconsistency between the *ECTM User's Guide & Reference Manual* and the *PT6A Maintenance Manual* in the critical area of when to respond to changes in ECTM data, with the *Maintenance Manual* requiring less significant deviations from baseline to initiate remedial action. The engine manufacturer stated that the *ECTM User's Guide & Reference Manual* was to be used for reference only, and that the operator should refer to the *Maintenance Manual* for specific guidelines.

2.3.4 Defences associated with CASA's surveillance processes

As discussed in Section 2.3.3, the engine manufacturer's process for incrementally increasing TBO had a built-in and ongoing method of confirming that appropriate maintenance processes were being conducted by the operator. By allowing a wider range of operators to extend TBOs to 5,000 hours, there was an onus on CASA to take measures to assure itself, during its surveillance activities, that operators who elected to extend TBOs had appropriate processes in place to comply with the requirements of the AD. Such surveillance activities would form an essential mitigator to offset the increase in TBO permitted by the AD. However, the available evidence indicates that CASA's surveillance system did not effectively address this issue. More specifically:

- There were no specific requirements or guidelines for CASA inspectors to review life extension programs during an operator audit.
- There were no specific guidelines to assist CASA inspectors to identify priority areas for consideration during surveillance activities.
- In this case, ensuring the operator had processes in place to comply with the requirements of AD/ENG/5 should have been a priority area for consideration during surveillance. The operator had elected to extend the TBO on its PT6A engines to 5,000 hours as permitted by AD/ENG/5, and it had a newly-approved maintenance organisation. The operator's chief engineer was also performing several different roles, including the role of maintenance controller from August 2001. In addition, during its audit on 20 to 23 August 2001, CASA had already identified that records for recurring airworthiness directives and recurring maintenance control were not being kept up to date.
- CASA was aware that, when the chief engineer was appointed as the maintenance controller in early August 2001, he had not received training in ECTM, and therefore was not qualified to conduct ECTM functions. CASA staff were also aware that an arrangement had been made to have the data analysed by the engine manufacturer's field representative. However, CASA did not apparently identify that this arrangement did not meet the requirements of the AD (see Section 2.3.3). There was no subsequent check by CASA to ensure that this arrangement was documented by the operator in the relevant manuals, or that the data was being submitted for analysis on a regular basis.

- Following the accident, CASA inspectors from the south-east Queensland region conducted a review of the engine condition monitoring programs of operators in their region, and found that a number of them were not complying with relevant requirements.

The investigation concluded that CASA's surveillance system was not sufficiently rigorous to ensure that the mitigators it had introduced within AD/ENG/5 for allowing TBO extensions were effective.

2.3.5 Defences associated with CASA's approval processes

As discussed in section 2.3.1, the maintenance organisation was experiencing problems with its level of maintenance resources. CASA had identified that it was important to consider whether a maintenance organisation had sufficient staff to conduct its required maintenance activities. However, CASA did not detect that there was a problem with the maintenance organisation's level of maintenance resources prior to the accident.

CASA's assessment of the operator for the initial issue of the Certificate of Approval was conducted in February 2001. This assessment was subjective and was not based on any formal consideration of the maintenance hours required to conduct the required maintenance. The operator's application listed only the chief engineer and an apprentice, with the maintenance controller function being performed by another employee. The available data indicated that this planned level of resources was inadequate to conduct the required maintenance for the operator's six twin-engine (turboprop) aircraft conducting RPT and charter operations (see Section 2.3.1).

An AME subsequently joined the organisation in March 2001. In August 2001, the maintenance controller resigned and the chief engineer was tasked with that additional function. The resource situation was probably at its most critical level after this time. However, CASA did not appear to consider maintenance resource issues when it approved the chief engineer to take on the additional role as maintenance controller. CASA also did not appear to identify that there was a problem with maintenance resources during its audit of the maintenance organisation conducted in August 2001, or during its process of reissuing the maintenance organisation's Certificate of Approval in November 2001.

The investigation found that CASA did not have any standard tools or guidelines to assist inspectors in making assessments of the suitability of a maintenance organisation's level of maintenance resources. Aircraft manufacturers and consultancy organisations provide information on the ratios of maintenance personnel required relative to flight hours for various aircraft types so that maintenance organisations can appropriately plan and schedule maintenance activities. Maintenance hours per flight hour ratios could be used as a basis for a standardised process of assessment.

2.4 Flight operations-related events and conditions

2.4.1 Aircraft performance

One witness heard an unusual noise from the aircraft at the same time that he saw the aircraft rotate. Another witness said the aircraft travelled about another 100 m down the runway after he heard the first unusual noise from the aircraft. Both witnesses were located about 250 m from the aircraft, which meant that what they heard would have occurred over half a second earlier because of the time taken for the sound to travel that distance. Therefore, based on the evidence available, it seems probable that the engine failure occurred just prior to or at the point when the aircraft became airborne.

Witnesses reported that the aircraft rotated about 50 to 100 m further down the runway than they considered normal for the operator's C90 aircraft. If the take-off roll was longer than normal, this may have been due to a number of factors. For example, when the engine lost power, the aircraft's acceleration would have been affected. As a result, if the engine lost power during the take-off roll, the normal rotation speed may not have been reached until later in the take-off roll. A longer than normal take-off roll may also have been a result of the pilot taking time to evaluate the situation before deciding to rotate the aircraft.

The aircraft's attitude during the brief period it was airborne was consistent with an asymmetric, low speed, flight situation. The abrupt left roll just before ground impact, and the steep nose-low attitude at impact, indicated a loss of control of the aircraft when the airspeed fell below the minimum control speed (V_{mca}, or 90 kts). Although there was no means of accurately establishing the speed profile during the flight, the aircraft attitude in the initial segment of the flight (left yaw, left-wing low, drifting left) also suggested that it was probable that the speed during that phase was never significantly above V_{mca}.

Airspeed is the most important factor in determining whether a pilot can maintain control of an aircraft, and whether an aircraft will be able to climb away with one engine inoperative. Several factors would have contributed to the aircraft's speed not being sufficient to maintain control during the accident flight, including the following:

- The left engine lost thrust-producing power just prior to, or at about the time the aircraft became airborne.
- The aircraft's speed when it became airborne was probably close to V_{mca}. This conclusion was based on the observed performance of the aircraft soon after it became airborne, as well as the operator's normal procedures. The investigation could not determine the normal rotation speed used by the pilot involved in the accident, or the exact speed at which the aircraft rotated on the accident flight. However, the operator published a rotation speed of 90 kts in the *Operations Manual*, and several of the operator's pilots reported that they rotated the aircraft between about 85 and 90 kts. The aircraft manufacturer specified a rotation speed of 96 kts for the accident aircraft's take-off weight.
- There was substantial aerodynamic drag because the landing gear remained extended and the left propeller was not feathered.
- The aircraft never attained the most appropriate attitude for achieving the best one-engine inoperative climb performance; that is, banked towards the operative engine.

It is generally accepted within the aviation industry that V_{yse} is the most appropriate target speed for multi-engine aircraft below 5,700 kg MTOW following an engine failure during initial climb, unless obstacle clearance is a requirement. The manufacturer specified in the *Approved Flight Manual* for the accident aircraft that the appropriate speed was V_{yse} (107 kts).

The manufacturer also specified that V_{xse}, the best one-engine inoperative angle-of-climb speed, was 96 kts. Therefore, it was technically possible that the aircraft could have been safely climbed if it had achieved this speed and was in the appropriate configuration. However, with an engine failure at about 90 kts, and by rotating the aircraft at about this speed, there was considerable doubt as to whether the aircraft could have been accelerated to obtain V_{xse}, and then maintain that speed, with the landing gear extended and the propeller of the inoperative engine unfeathered. Even with a timely response from the pilot, it would take several seconds before the aircraft could be appropriately configured. Operation at V_{xse} also results in a reduced speed margin above V_{mca}.

2.4.2 Decision to continue the takeoff

An engine failure in a multi-engine aircraft at about the point of becoming airborne is one of the most challenging situations that a pilot can encounter. For most multi-engine aircraft below 5,700 kg, such as the C90, the aircraft cannot climb with one-engine inoperative until the aircraft is correctly configured and the specified speed is achieved.

Therefore, when deciding whether to continue the flight or reject the takeoff, pilots need to ensure that they have sufficient speed to be able to accelerate to the appropriate one-engine inoperative climb speed, which in this case was V_{yse}. In instances where the aircraft speed is below V_{yse} and the landing gear has not been retracted and/or the propeller not feathered, then there is little prospect of the aircraft being able to accelerate to this speed and safely climb away.

The investigation was not able to determine when the pilot made the decision to continue with the flight. Research from simulator trials indicated that pilot response times for this type of situation would be about 2 seconds for pilots who knew they were going to have an emergency during the take-off roll. In a real life situation, the average response time would probably be greater, as the pilot would not have the same level of expectancy. However, pilot response times to engine problems are also quite variable.

As discussed in Section 2.4.1, it seems probable that the aircraft's speed when it became airborne would have been close to V_{mca}. With an engine failure at about this speed, the safest course of action would be to reject the takeoff in accordance with the procedures specified in the *Approved Flight Manual*. This manual, which had precedence over the operator's procedures, stated that the takeoff should be rejected if the engine failure occurred prior to the 'take-off speed' (100 kts).

Although in some cases a rejected takeoff will result in the aircraft overrunning the runway and perhaps sustaining substantial damage, the consequences associated with such an accident will generally be less serious than a loss of control after becoming airborne.

It must be emphasised that the pilot on this occasion was exposed to a rare situation that involved many complex issues and which required very rapid detection, decision-making, and follow-up actions for there to have been any prospect of a successful outcome. Many factors may have contributed to his decision, including the following:

- The potential of a runway overrun at Toowoomba would have been particularly salient given that the accelerate stop distance available on runway 29 was 1,121 m and the accelerate stop distance required (ASDR) was about 1,300 m. The relatively high likelihood of an overrun accident with an engine failure late in the take-off sequence at Toowoomba may have predisposed the pilot to consider that the only way of avoiding an accident was to continue the takeoff. In this case a number of factors would have influenced the accelerate stop distance if the pilot rejected the takeoff, including the aircraft speed when the pilot made the decision (which would have reduced ASDR if less than 100 kts), the aircraft's position on the runway when the pilot made the decision, whether the pilot would have used propeller reversing (which would have reduced ASDR), the slope of the western end of the runway and the area beyond the runway (which would have increased ASDR), and the arresting effect of the fence at the aerodrome boundary (which would have reduced ASDR).

- The longer the pilot took to recognise the nature of the emergency situation, the greater the risk of a runway overrun accident occurring. It is possible that the increasing certainty of an overrun accident as time passed increased the likelihood that the pilot would consider that the only way of avoiding an accident was to continue the takeoff.
- The physical characteristics of Toowoomba aerodrome resulted in a pilot not being able to see the end of the runway and visually assess the distance remaining until the aircraft was about 350 m from the runway end. However, buildings beyond the end of the runway became visible at about 450 m from the end of the runway. The appearance of the buildings and the inability to see much of the remaining runway at about the time of the engine failure may have led the pilot to think that there was less runway remaining than there actually was.
- The pilot may have believed that he had sufficient speed to safely continue the flight. The operator's procedures specified a rotation speed of 90 kts, which was below the manufacturer's specified speed. The operator's procedures also stated that, if an engine failure occurred after liftoff, then the recommended course of action was to continue if conditions precluded an immediate landing. The pilot may have interpreted the increasing certainty of an overrun accident as precluding an immediate landing (see also Section 2.5.1). The extent to which the pilot was aware of the importance of attaining the appropriate one-engine inoperative climb speed could not be determined.
- The pilot was almost certainly experiencing a very high workload following the engine failure, as well as possible confusion and stress. Error rates when making rapid decisions under such circumstances will be relatively high.
- Workload and error rate can be reduced if the pilot has had prior experience in making the decision. The emergency situation that the pilot encountered during the accident was one that he had almost certainly not encountered previously. The lack of training for this situation was not unusual for pilots endorsed on this category of aircraft, where the level of endorsement and recurrent training was generally limited to classroom type discussions and unrepresentative exercises in the aircraft.
- Workload and error rate can also be reduced if the pilot has conducted a pre-takeoff briefing which considered the relevant scenario. The extent to which the pilot normally conducted a suitable briefing could not be determined.

2.4.3 Pilot actions after takeoff

The landing gear being in the extended position would have had a significant effect on aircraft one-engine inoperative performance during the accident flight. The reasons for the landing gear not being retracted could not be determined. The pilot would have been experiencing a very high workload at this time, which may have distracted him from carrying out all of the required emergency actions.

The unfeathered status of the left propeller does not lead to any clear conclusions regarding the pilot's actions. It is possible that the pilot retarded the left engine power lever as one of his actions in attempting to deal with the engine failure; an action that would have disarmed the auto-feather system. However, as discussed in Section 2.2.1, there was no evidence to confirm whether such an event occurred, and there were other possible explanations for the propeller not being feathered.

Witnesses reported that the aircraft initially rolled to the left, and then returned to a wings level attitude. This indicated that the pilot was not incapacitated during the flight, which was consistent with the available medical and pathological information.

2.5 Flight operations-related defences

2.5.1 Procedures for responding to an engine failure during takeoff

In multi-engine aircraft with a MTOW below 5,700 kg, there is a critical area during takeoff between liftoff and the aircraft achieving V_{yse} where one-engine inoperative performance is marginal. An operator needs to have clearly defined procedures for responding to engine failures during this part of the initial climb, and these procedures need to include an appropriate decision speed or decision point as to when to reject the takeoff or continue with the flight.

The operator's procedures emphasised the importance of a decision speed, at which the takeoff would be continued in the event of an engine failure. However, the procedures did not clearly define what the decision speed was for the C90, and company pilots had various recollections about what was the appropriate decision speed.

The operator's procedures stated that if the engine failure occurred before liftoff the takeoff would be rejected, but if the failure occurred after liftoff the takeoff would be continued 'if conditions preclude an immediate landing'. In the absence of any other clarifying information, these procedures could be interpreted as suggesting that the decision point for deciding whether to continue the takeoff was at rotation. This interpretation would be reinforced at Toowoomba aerodrome given the limited length of the main runway, which meant that it was unlikely that a landing after becoming airborne could be conducted on the runway.

Runway length, runway slope and the nature of the surrounding area were all factors at Toowoomba that had a potential impact on decision-making regarding whether to reject or continue a takeoff. Such issues were not unique to Toowoomba. Nevertheless, as Toowoomba was the operator's main operational base, there was an onus on the operator to have clearly defined procedures to handle emergencies during takeoff at that aerodrome.

The suitability of the operator's procedures for the C90 was further degraded by its specified rotation speed of 90 kts, which was less than that specified by the aircraft manufacturer (96 kts for the accident flight). The use of this rotation speed, which was the same as V_{mca}, had the effect of compromising the one-engine inoperative performance capability of the aircraft following an engine failure at liftoff.

The aircraft manufacturer's specified procedures for responding to an engine failure for LQH stated that the takeoff should be rejected below the 'take-off speed', specified as 100 kts. This speed provided a greater margin of safety if the pilot elected to continue the flight. The aircraft manufacturer's procedures for SQH and later serial number aircraft was effectively the same as the operator's procedures, except that the specified rotation speeds were higher, and therefore the manufacturer's procedures provided a greater margin of safety if the pilot elected to continue the flight.

Opinions amongst pilots and operators vary widely regarding the considerations and procedures to be taken in the event of an engine failure during takeoff in multi-engine aircraft below 5,700 kg MTOW. The issue is complex with many factors involved, including runway characteristics, aircraft performance, and surrounding topography. There is currently no formal advisory material issued by CASA to Australian operators and pilots regarding the most appropriate ways to consider the management of engine failures during takeoff in these aircraft. Although a range of educational materials on this topic are available, a formal advisory document would have the potential to ensure that operators and pilots are more appropriately prepared for such events.

2.5.2 Training for responding to an engine failure during takeoff

There is a requirement for pilots to practice recognition and response to engine failures during aircraft endorsement training and regular checks, such as base checks. For Australian general aviation and low capacity RPT operations, this training and checking is usually conducted in an actual aircraft, either at low speed on the runway, or at a safe height. This means that the training and checking process is not testing the pilots' ability to make a decision whether or not to reject a takeoff in the event of an engine failure during a critical phase of flight. The lack of training in this area reinforces the need for operators to have clearly defined and appropriate procedures, and the need for CASA to develop formal advisory material in this area for operators and pilots.

CASA advised that there are no flight simulators or synthetic trainers in Australia that can be used for simulating asymmetric handling during an emergency for multi-engine aircraft below 5,700 kg MTOW. However, CASA's advice appeared to focus on aircraft handling issues, and did not appear to consider the capability of existing synthetic trainers to develop the pilot's decision-making ability for such emergencies. If such devices could be used for this type of decision-making training, it could assist in overcoming a significant limitation in current pilot training and checking processes for multi-engine aircraft below 5,700 kg MTOW.

2.5.3 Aerodrome design

The 60 m runway strip area beyond the end of runway 29 at Toowoomba complied with the standard required by the CASA RPA. However, it did not comply with the ICAO standard, which considered the runway strip and RESA separately, and required a Code 2 aerodrome RESA to be 90 m in length. If the overrun area had met the ICAO standard, it would have extended 150 m beyond the runway end. There was an additional 40 m beyond the runway strip and before the boundary fence, but this sloped down at 9 per cent, a greater slope than the ICAO recommended slope for a RESA of 5 per cent. Notwithstanding, Australian aerodrome operators were only required to comply with the CASA RPA requirements.

Had runway 29 at Toowoomba conformed to the ICAO standard and recommended practice, the risk associated with an overrun would have been reduced due to the RESA being longer and limited to a maximum down slope of 5 per cent. Whether an additional 50 m of clear area beyond the end of the runway, within the recommended slope, would have led the pilot to reject the takeoff instead of continuing the flight could not be determined.

3 CONCLUSIONS

3.1 Findings

3.1.1 Maintenance-related issues

1. The left engine failed just prior to, or at about, the time the aircraft became airborne.
2. The damage to the left engine was consistent with the fracture and release of one or more compressor turbine blades, which would have initiated the release of other compressor turbine blades and their subsequent impact with adjacent and downstream components, resulting in a loss of useful power.
3. There were no indications that the engine failure was due to manufacturing defects, metal fatigue, foreign object damage during the flight, or the quality or quantity of the fuel on board the aircraft.
4. Examination of the compressor turbine blades from the left engine indicated that they had been exposed to higher than normal operating temperatures in the period leading up to the accident.
5. The engine failure occurred at 3,556.0 hours since the last overhaul, which was within the 3,600 hours time between overhaul specified by the engine manufacturer.
6. The aircraft's engines were operating on a life extension to 5,000 hours time between overhaul in accordance with the requirements of Airworthiness Directive AD/ENG/5. Those requirements included that the engines be subject to an engine condition trend monitoring (ECTM) program.
7. The pattern of ECTM data from the left engine indicated that a potentially significant problem had been developing in the cold section of the engine over the months preceding the accident.
8. The ECTM data for the right engine indicated that a potential problem had also been developing in the cold section of that engine for a period of time.
9. Apart from issues associated with the left engine, there were no indications of any fault in any aircraft system that may have contributed to the accident.
10. Prior to March 2001, maintenance on the operator's aircraft was conducted by an external maintenance organisation. From March 2001, maintenance was conducted by a newly formed internal maintenance organisation.
11. The last maintenance on the left engine most probably occurred on 7 June 2001, and this maintenance included a compressor performance recovery wash. Based on the requirements of AD/ENG/5 and the manufacturer's *Maintenance Manual*, another performance recovery wash should have been conducted no later than 7 September 2001.
12. In the 4 months prior to the accident, the ECTM data was not being recorded or analysed as frequently as required by AD/ENG/5 or the engine manufacturer's specifications.
13. The ratio of the operator's available maintenance personnel resources relative to the maintenance resources reasonably required, resulted in the operator's chief engineer experiencing a significant workload. This workload increased after he also became the operator's maintenance controller on 3 August 2001.

14. The operator did not have personnel who were suitably qualified, or have a formal arrangement with a suitably qualified person, to conduct analysis of its ECTM data.
15. The operator's processes for maintenance scheduling were not adequate to ensure that maintenance tasks were conducted when required.
16. CASA surveillance had not detected problems with the operator's ECTM program prior to the accident. Following the accident, problems were detected with the ECTM programs of several operators, including the operator of LQH.
17. The introduction of AD/ENG/5 allowed life extensions for engines to be approved for PT6A engines in Australia under less restrictive circumstances compared with those required by the engine manufacturer.
18. CASA's surveillance system was not sufficiently rigorous to ensure that the mitigators it had introduced within AD/ENG/5 for allowing TBO extensions were effective.
19. The CASA system for approving maintenance organisations and maintenance controllers did not appropriately consider the operator's maintenance resource requirements.

3.1.2 Flight operational-related issues

1. The pilot was appropriately licensed to conduct the flight.
2. The pilot held a valid medical certificate, and it was unlikely that any medical or physiological factors adversely influenced the pilot's performance.
3. Following the engine failure, the take-off manoeuvre continued and the aircraft became airborne.
4. The aircraft's speed when it became airborne was probably close to V_{mca} (90 kts).
5. The landing gear remained extended and the left propeller was not feathered, both of which affected the one-engine inoperative performance of the aircraft.
6. The aircraft flight path was typical of an asymmetric, low speed flight situation.
7. A number of factors could have influenced the pilot's decision to continue with the takeoff, including the timing and nature of the engine failure, the nature of the operator's procedures, the limited length of the runway, and the visual appearance of the runway and buildings beyond the runway at the time of the engine failure.
8. The operator specified a rotation speed of 90 kts, which was less than the 96 kts rotation speed specified by the aircraft manufacturer for King Air C90 aircraft with later serial numbers than LQH. The CASA *Approved Flight Manual* for LQH did not specify a rotation speed.
9. The operator's specified rotation speed had the effect of degrading the one-engine inoperative performance capability of the aircraft during takeoff.
10. The aircraft manufacturer's specified procedures for responding to an engine failure in LQH stated that the takeoff should be rejected below the 'take-off speed', specified as 100 kts.
11. The operator's procedures for C90 aircraft did not provide appropriate guidance for pilots regarding decision speeds or decision points to use for an engine failure during takeoff.
12. Formal CASA guidance material regarding engine failures in multi-engine aircraft below 5,700 kg MTOW was not available.
13. The level of pilot training available for emergencies during critical phases of flight in multi-engine aircraft below 5,700 kg MTOW was less than desirable.

14. Runway 29 at Toowoomba satisfied the CASA requirements but did not meet the ICAO standard.

3.2 Significant factors

1. The left engine failed during a critical phase of the takeoff. The failure was probably the result of a developing problem in the cold section of the engine, which was not detected or corrected due to several compounding deficiencies in the operator's maintenance system.
2. The aircraft manufacturer's specified procedures for responding to an engine failure in LQH stated that the takeoff should be rejected below the 'take-off speed', specified as 100 kts. The short flight continued at a speed close to V_{mca} (90 kts), and the aircraft was not configured to minimise drag.
3. Control of the aircraft was lost in circumstances where recovery was not possible and the subsequent ground impact and fire was not considered survivable.

4 SAFETY ACTION

Central to ATSB's investigation of aviation accidents and incidents is the identification of significant safety issues in the civil aviation environment. The Bureau issues recommendations to regulatory authorities, operators, manufacturers or other relevant agencies in order to address safety issues. Recommendations may be issued in conjunction with ATSB reports or independently. A safety issue may lead to a number of similar recommendations, each issued to a different agency.

The ATSB does not have the resources to carry out full cost-benefit analysis of every recommendation. The cost of any recommendation must always be balanced against its benefits to safety, and aviation safety involves the whole community. Such analysis is a matter for the body to which the recommendation is addressed (for example, CASA, in consultation with the industry).

Recommendations should not be seen as a mechanism to apportion blame or liability. They are directed to those agencies that should be best able to give effect to the safety enhancement intent of the recommendations, and are not, therefore, necessarily reflective of safety issues within those agencies.

4.1 The aircraft operator

A number of safety issues identified during the investigation related to the aircraft operator. It would normally be expected that an operator would undertake safety actions to address such issues, as a result of its own initiatives or as a result of ATSB recommendations. However, subsequent to the accident the operator ceased operations.

4.2 Civil Aviation Safety Authority

4.2.1 Airworthiness Directive AD/ENG/5

Amendment 8 of AD/ENG/5 was issued on 3 June 2003, with a compliance date of no later than 1 January 2004. This amendment made changes to Appendix A of the AD. The appendix was restricted to aircraft conducting operations other than aerial agriculture or fire fighting. Similar maintenance requirements for aircraft operated in aerial agriculture and fire fighting operations were outlined in Appendix B of the AD. Paragraph 2 of Appendix A was modified to more clearly elaborate the requirements of ECTM. This paragraph stated the following:

> The engine shall be on an Engine Condition Trend Monitoring (ECTM) program, including data collection, analysis and follow up actions. The program shall be in accordance with the Pratt and Whitney Canada ECTM Users Guide and Reference Manual (PWC P/N 3031900) and includes requirements for qualification and training for personnel conducting ECTM;

The Appendix included more detailed overhaul requirements for accessories and inspection of safety critical components. The appendix also introduced the following requirement for operators:

> The maintenance program shall be reviewed and revised as required at periods not to exceed 2 years taking into consideration all major defects and defects that affect engine durability. These defects included in the maintenance program review shall be reported to CASA after each review under Major Defect Reporting (MDR) system referring to AD/ENG/5.

4.2.2 Airworthiness surveillance processes

In April 2002, CASA issued a direction under CAR 1988 r. 38 for the operator to amend its system of maintenance to not use the provision of paragraph 2.4 of AD/ENG/5 Amendment 7 to extend the TBO of its PT6A engines to 5,000 hours. The operator was directed to modify the required TBO of its engines to 3,600 hours. For engines with a TBO greater than 3,600 hours, an overhaul was required to be conducted within 200 hours (if TBO was already between 3,400 and 4,000 hours) or within 100 hours (if TBO was already greater than 4,000 hours). Similar requirements were issued for the operator's other turbine engines.

During the ATSB investigation, CASA advised that it had reviewed the ECTM programs of other operators in the south-eastern Queensland region. However, at the date of this investigation report, CASA had not conducted a national audit to determine the level of compliance with the requirements of AD/ENG/5.

On 16 April 2004, CASA advised that its ECTM compliance program had been strengthened by:

- The participation of several CASA compliance staff in ECTM training conducted by PWC;
- A program to develop guidance material for ECTM compliance assessment;
- A program to improve the awareness of CASA staff and industry on the critical nature of ECTM; and
- An article has been published in the [CASA] magazine… [*Flight Safety Australia*] on ECTM.[59]

The ATSB remains concerned that there continues to be a fundamental problem that CASA has allowed all types of operators to extend TBOs for PT6A engines without an effective process or mechanism for confirming compliance with the mandated maintenance requirements. The ATSB is also concerned that operators using other types of turbine engines may be conducting engine condition monitoring as part of their approved systems of maintenance but not using the required or recommended procedures. Consequently, the ATSB issues the following safety recommendations:

Safety Recommendation R20040064

The ATSB recommends that CASA conduct a national review of the level of operator compliance with the requirements of mandatory turbine engine condition monitoring programs, particularly for passenger carrying operations.

Safety Recommendation R20040065

The ATSB recommends that CASA review its surveillance processes to ensure that, during future surveillance activities, priority is given to confirming operator compliance with the requirements of mandatory turbine engine condition monitoring programs, particularly for passenger carrying operations.

Safety Recommendation R20040066

The ATSB recommends that CASA review its airworthiness surveillance processes and Certificate of Approval assessment processes to ensure that it provides adequate guidelines to assist CASA inspectors to identify priority areas for consideration during surveillance and approval activities, such as programs for compliance with the requirements of Airworthiness Directives.

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[59] The article, titled 'A stitch in time', was published in the January-February 2004 issue of *Flight Safety Australia*.

4.2.3 Processes for approving maintenance controllers

On 10 March 2004, CASA advised that its Airline Operations Branch had a revised Maintenance Controller Assessment Process in place for approximately 12 months. In addition, CASA's Regulatory Services Branch was working on formal guidance material for inclusion in the Air Operator's Certification Manual, and this material was expected to be completed by mid 2004.

4.2.4 Processes for approving maintenance organisations

Safety Recommendation R20040067

The ATSB recommends that CASA review its airworthiness surveillance processes and Certificate of Approval assessment processes to ensure that it provides specific guidelines to assist CASA inspectors to assess whether a maintenance organisation has adequate personnel resources to conduct its required activities.

4.2.5 Processes for managing engine failures

The ATSB notes that CASA has published articles discussing some aspects of handling engine failures in multi-engine aircraft in its *Flight Safety Australia* magazine. Although educational material will always be useful, the ATSB also notes that such material may have a limited time span of effectiveness. Consequently the ATSB issues the following recommendations:

Safety Recommendation R20040068

The ATSB recommends that CASA consider providing formal advisory material for operators and pilots, based on relevant research and publications, about managing engine failures and other emergencies during takeoff in multi-engine aircraft below 5,700 kg MTOW. This material should include the factors to be considered by operators when developing procedures for responding to such emergencies.

Safety Recommendation R20040069

The ATSB recommends that CASA consider and evaluate options to improve the suitability of industry practices for training pilots to make appropriate decisions when responding to engine failures and other emergencies during critical phases of flight in multi-engine aircraft below 5,700 kg MTOW. This review should include an assessment of the suitability of utilising synthetic training devices for the purpose of training pilots to make decisions regarding emergencies.

4.2.6 Aerodrome design standards

In May 2003, CASA replaced the *Rules and Procedures for Aerodromes* with Civil Aviation Safety Regulation (CASR) 1998 r. 139 – Aerodromes. The regulation was supported by the *Manual of Standards Part 139 – Aerodromes* (MOS 139). MOS 139 required a RESA to be provided for all instrument runways and code 3 and 4 non-instrument runways. The MOS adopted the ICAO standard that a RESA should commence from the end of the runway. However, MOS – 139 only required a 60 m RESA for code 2 runways (the ICAO standard stated that '… a runway end safety area shall extend from the end of a runway strip to a distance of at least 90 m.').

MOS 139 also noted that, where it was not practicable to provide the full length RESA, an engineering solution may be approved to enhance aircraft deceleration. In that case aerodrome operators were advised to liaise with the relevant CASA office.

The MOS 139 RESA standard applied to all new runways, and existing runways when lengthened. CASA advised that '…under the transitional arrangements, aerodrome operators have three years to change to the new CASR 139 Regulations'.

On 16 April 2004, CASA advised that Australia had filed differences with ICAO regarding Annex 14.

4.3 The aerodrome operator

As a result of this accident, the ATSB makes the following recommendation to the aerodrome operator:

Safety Recommendation R20040070

The ATSB recommends that the Toowoomba City Council liaise with CASA to evaluate an engineering solution to enhance aircraft deceleration in the runway end safety area of runway 11/29 at Toowoomba aerodrome.

Appendix A: Findings of the initial examination of LQH engines

Findings of the engine examination:

Component	***Left engine***	***Right engine***
External cases	Reduction gearbox, gas generator cases were intact but heat damaged. Accessory gearbox housing was destroyed. Exhaust stub flanges showed evidence of impact from separated turbine blades	Reduction gearbox housing was essentially intact.
Power control and reversing linkage	No evidence of pre-impact fault.	Examination was not possible due to impact and fire damage.
Pneumatic lines	No evidence of pre-impact fault.	Examination was not possible due to impact and fire damage.
Chip detectors and filters	Chip detector magnetic elements were destroyed. Oil filter was not located. Damage to fuel filter precluded examination.	Not examined.
Compressor section	First stage blades showed no distress. Shroud showed light circumferential scoring from contact with the blade tips.precluded examination.	First, second, and third stage blade tips displayed circumferential rubbing from contact with their adjacent shrouds. The shrouds displayed circumferential rubbing. The centrifugal impeller displayed heavy circumferential rubbing.
Combustion chamber	No indications of operational distress.	No indications of operational distress.

Component	*Left engine*	*Right engine*
Exit ducts	The flame patterned indications on the large exit duct appeared normal. Neither the large, nor the small exit ducts showed signs of operational distress.	No indications of operational distress.
Turbine section	See Section 1.16.	The compressor turbine blade airfoils were fractured uniformly at the roots due to radial contact with the shroud and housing. The power turbine shroud displayed heavy circumferential scoring from radial contact with the power turbine blade tips. Some power turbine blades were partially or fully displaced from their fir tree slots. The remaining blades were fractured at heights varying from the root to approximately one half stand due to contact with the shroud and vane ring.
Gearboxes	The reduction gearbox showed indications of operational distress. The accessory gearbox showed no indication of operational distress.	Not disassembled.
Fuel control unit	The fuel control unit could not be examined because of fire and heat damage.	Not located.
Propeller and overspeed governor	The drive splines were intact	Not disassembled.

Appendix B: TSB report (examination of LQH engines and propellers)

1.0 INTRODUCTION

1.1 A Beechcraft King Air C90 aircraft, registration VH-LQH, crashed shortly after take-off, killing all occupants. Witnesses reported hearing an unusual sound about the time the aircraft became airborne.

1.2 The engines (Pratt & Whitney Canada (PWC) PT6A-20A) were torn down at an engine overhaul facility and subsequently shipped to the Engineering Branch Laboratory of the Transportation Safety Board of Canada for assessment of operational condition at impact.

2.0 EXAMINATION AND ANALYSIS

2.1 The components from both engines were laid out on the floor of the examination shop to facilitate the physical analysis (Figure 1). The engines had suffered not only from extensive deformation due to the contact with terrain but also from an intense fire that had broken out upon ground impact. The observations made at the site and the engine teardown suggested that the left engine had lost power prior to impact. It was therefore decided to inspect the components from the left engine (S/N 24105) first (Figures 2 through 9).

2.2 The left propeller assembly was severely damaged by fire to the point of partial meltdown of the blades (Figure 2). The deformation to the blade structures remaining was consistent with ground impact without power input. An attempt was made to determine whether the propeller was feathered at impact. This will be covered in the discussion part of the report.

2.3 The housing of the reduction gearbox was essentially intact. The propeller shaft was intact. The propeller governor, overspeed governor, and Np tachometer generator were in place, with minor impact and fire damage. The exhaust duct was compressed to approximately 3⁄4 of its normal length. The forward flange was displaced to the right and downward in relation to the rear flange. The exhaust stub flanges displayed indentations characteristic of contact on the interior surfaces with separated turbine blade debris. The gas generator case housing was intact. The compressor inlet case support struts were heat deformed. The fuel manifold and compressor bleed valve were intact, with fire and heat damage. The accessory gearbox rear housing was completely fire consumed. Assorted gearing and the high pressure fuel pump/fuel control unit which were recovered showed severe fire and heat damage.

2.4 The compressor 1st stage was examined in-situ. The 1st stage blades displayed no signs of distress. The shroud displayed light circumferential scoring due to radial contact with the blade tips. The combustion chamber liner displayed no indications of operational distress. Both the large and small exit ducts displayed no indications of operational distress. The flame pattern indications appeared normal. The compressor turbine guide vane ring airfoil leading edges displayed normal operation heat erosion. The airfoil trailing edges and suction faces displayed heavy gouges, and fractures of the outer spans, characteristic of contact with separated compressor turbine blade debris. The compressor turbine shroud displayed heavy gouges and scoring characteristic of contact with separated compressor turbine blade debris.

2.5 The compressor turbine (P/N 3013511, S/N A3726. Blade P/N's 3023401) displayed signs of heavy damage (Figure 10). The blade airfoils were fractured at varying heights from the root to approximately half span (Figure 11). Under unaided visual and macroscopic inspection, the fracture surfaces displayed general features of overload fracture, with collateral mechanical damage (Figure 12). Blades 9, 11 and 50 were removed from the wheel for closer examination. Blade 11 which represents the short blade remnant exhibited an oxidized interdendritic fracture topography (Figure 13). The longer blade remnants such as blade 9 were characterized by slant fractures at the leading and trailing edges with a mechanically damaged centre section (Figure 14). Detailed examination of all blades revealed no evidence of any time dependent failure mechanism (such as fatigue or creep). Blade 9 was subsequently sectioned lengthwise, polished and etched. Figure 15 shows an interdendritic propagation of a secondary crack. Examination at high magnification indicated that re-solution of the gamma prime phase had taken place (Figures 16 and 17) which would indicate operation at a higher than normal temperature.

2.6 Assistance with the interpretation of the fractographic and metallographic findings was sought from the Materials Laboratory at P&WC. The analysis conducted there verified the blade fractures to be due to overload, with no indications of fatigue or material creep. Scanning electron microscope examination of the gamma prime morphology confirmed the blades to have been exposed to a high operating temperature. The material composition was found to be in accordance with engineering drawing requirements.

2.7 The disc upstream side outer rim was circumferentially rubbed and scored across approximately one third of the disc circumference due to contact with the compressor turbine guide vane ring. The disc downstream side displayed light circumferential rubbing due to contact with the interstage baffle. The disc hub was circumferentially scored and deformed due to contact with the power turbine disc, through the interstage baffle.

2.8 The power turbine guide vane ring airfoils were fractured due to displacement of the inner drum. The leading edges were lightly nicked due to contact with upstream debris. The trailing edges were nicked, gouged, and circumferentially scored due to contact with the power turbine. The inner drum was displaced aft and fractured around the lower circumference. The interstage baffle was displaced from the inner drum and pressed on to the compressor turbine disc. The baffle upstream side displayed light circumferential rubbing, with concurrent static imprint marks, due to axial contact with the compressor turbine disc. The baffle upstream side displayed heavy circumferential scoring, with frictional heat discoloration, due to axial contact with power turbine disc. The inner cup was circumferentially machined away due to contact between the compressor and power turbine discs.

2.9 The power turbine shroud displayed heavy circumferential scoring, with frictional heat discoloration, due to radial contact with the power turbine blade tips. The power turbine was displaced to the left and aft due to deformation of the power turbine shaft and housing. The blade platforms across approximately two thirds of the disc circumference were axially displaced forward from their fir tree slots, with the remaining blades partially displaced, due to contact with the power turbine guide vane ring. The remaining blades were fractured at heights varying from the root to approximately two thirds span. The leading edges were heavily nicked and gouged. The disc upstream side displayed heavy circumferential rubbing and machining due to axial contact with the power turbine guide vane and compressor turbine disc.

2.10 The power turbine shaft and housing was deformed sharply to the right. The rear cover remained attached to the power turbine disc. The cover displayed heavy circumferential scoring due to contact with the displaced power turbine blade platforms. The 1st stage sun gear coupling was intact. The No. 3 bearing inner race was displaced aft from the inner race and cage, releasing the rollers. The inner and outer race, cage, and rollers displayed no indications of operational distress. The No. 4 bearing outer race retaining bolts were impact fractured.

2.11 The 1st and 2nd stage gearing of the reduction gearbox were examined in-situ, and displayed no indications of operational distress. Similarly, the recovered accessory gearbox gearing displayed no indications of operational distress. The input shaft coupling was intact.

2.12 The right hand engine (S/N 20577 Gas Generator, S/N 21072 Power Section) displayed severe impact damage and fire damage, including structural separation of the accessory gearbox (Figures 18 through 24). The reduction gearbox housing was essentially intact. The propeller shaft was intact. The propeller governor, overspeed governor, and Np tachometer generator were in place, with impact and fire damage. The exhaust duct displayed severe compressional deformation. The forward flange was displaced to the right and upward in relation to the rear flange. The housing was ruptured around the lower circumference. The gas generator case housing displayed severe compressional deformation. The compressor inlet case was fractured from flange “F”, and had remained with the accessory gearbox. The fuel manifold and compressor bleed valve were intact, with fire and heat damage. The accessory gearbox housing displayed heavy fire damage.

2.13 Compressor 1st, 2nd, and 3rd stage blade tips displayed circumferential rubbing due to contact with their adjacent shrouds. A number of the 3rd stage blades were deformed away from the direction of rotation due to deformation of the shroud housing. Compressor 1st, 2nd, and 3rd stage shrouds displayed circumferential rubbing, with frictional heat discoloration, due to contact with their adjacent blade tips. The majority of the stators were deformed into the direction of rotation due to contact with their adjacent spacers. Compressor 1st, 2nd, and 3rd stage spacers displayed circumferential scoring due to contact with the stator vane tips.

2.14 The centrifugal impeller displayed heavy circumferential rubbing, with frictional heat discoloration and material smearing, due to contact with the impeller shroud. The centrifugal impeller shroud displayed heavy circumferential rubbing, with severe frictional heat discoloration and material smearing, due to contact with the centrifugal impeller.

2.15 The combustion chamber liner displayed heavy impact deformation. There were no indications of operational distress. The large exit duct displayed no indications of operational distress. The flame pattern indications appeared normal. The small exit duct displayed heavy impact deformation. There were no indications of operational distress.

2.16 The compressor turbine guide vane ring airfoils were impact fractured around the upper circumference. The vane segments were partially separated around the lower circumference. The airfoils displayed no indications of operational distress. The compressor turbine shroud displayed heavy impact deformation. The shroud also displayed heavy circumferential scoring due to contact with the compressor turbine blades. The compressor turbine blade airfoils were fractured uniformly at the roots due to radial contact with the shroud and housing. The disc downstream side displayed heavy circumferential rubbing, with frictional heat discoloration, due to contact with the power turbine guide vane ring and interstage baffle. The disc hub was circumferentially machined due to contact with the power turbine disc, through the interstage baffle.

2.17 The power turbine housing displayed heavy impact deformation. The power turbine guide vane ring and interstage baffle airfoils and inner drum were obliterated due to contact between the compressor and power turbines. The interstage baffle was displaced from the inner drum. The baffle upstream side displayed heavy circumferential rubbing, with frictional heat discoloration, due to axial contact with the compressor turbine disc. The baffle upstream side displayed heavy circumferential scoring, due to axial contact with power turbine disc. The inner cup was circumferentially machined away due to contact between the compressor and power turbine discs. The power turbine shroud displayed heavy circumferential scoring, due to radial contact with the power turbine blade tips.

2.18 The power turbine itself was displaced upwards and to an approximate 45 degree angle to the engine centreline due to deformation of the power turbine shaft and housing. The disc was extracted from the housing to facilitate the inspection. A number of blade platforms were axially displaced forward from their fir tree slots, with the remaining blades partially displaced, due to contact with the power turbine guide vane ring. The remaining blades were fractured at heights varying from the root to approximatelyhalf span due to contact with the shroud and vane ring. Many of the blade roots had ended up embedded in a pool of molten aluminum as a result of the post crash fire. The disc upstream side displayed heavy circumferential rubbing and machining due to axial contact with the power turbine guide vane and compressor turbine disc.

2.19 Assistance from the propeller manufacturer was sought to interpret the physical evidence found with both propeller assemblies (Figures 10 and 18). The interpretation was hampered by extensive fire damage. The left propeller had heavy impact damage, severe fire damage, and several parts were missing. Blade butt impressions indicated approximately 25.7° and 40.7° blade angles. There were marks on the cylinder at feather and at an approximately 60° blade angle. There was no meaningful information concerning blade bending or twisting. The left propeller was found in the feather position after impact. Therefore, had the left propeller been feathered prior to impact, it does not seem logical to find witness marks at positions other than feather. It is much more likely that the propeller was at 25.7° or a lower blade angle and was driven toward higher angles during the impact sequence. (This is a common finding in accidents where one or more blades is bent forward of the plane of rotation. The bending direction could not be determined in the left propeller blades.) The right propeller had numerous missing parts and extensive fire damage. The only pertinent facts were that two of the blades were bent aft and one blade was twisted toward low pitch. The blade twisting suggests that it was rotating at the time of impact.

3.0 DISCUSSION

3.1 The left hand engine compressor turbine blades were fractured at varying heights from the roots to approximately half span. Materials analysis determined the blade fractures to be characteristic of overload separation. The blade microstructure indicated that the blades had been exposed to excessive operating temperatures. The blade material was determined to meet engineering drawing requirements, and no original material defects were observed. The remaining compressor turbine blade airfoils, the compressor turbine guide vane ring and all adjacent and downstream components displayed extensive mechanical damage due to contact with the separated compressor turbine blade debris.

3.2 The power turbine shroud and the interstage baffle displayed heavy circumferential scoring and machining due to their making contact with power turbine under impact loads and external housing deformation. Examination of Engine Condition Trend Monitoring (ECTM) data indicated a 20° C rise in interturbine temperature (ITT) from the base line figure during the period from June to November 2001. There was no record of any investigative or corrective action taken during this time.

3.3 The right hand engine compressor rotor, the compressor turbine, and the power turbine displayed severe circumferential rubbing and machining, with circumferential deformation and fractures of the compressor and power turbine blade airfoils, due to contact with their adjacent static components under impact loads and external housing deformation. There were no indications of any operational distress to any of the right hand engine components.

3.4 Severe fire damage to the left hand engine propeller assembly precluded a meaningful reconstruction of the blade orientation prior to impact. From the available physical evidence evaluated by the propeller manufacturer and the associated power turbine damage pattern it appears that the propeller was not feathered.

4.0 CONCLUSIONS

4.1 The damage pattern observed in the left hand engine is consistent with a blade release event from the compressor turbine. Extensive mechanical damage tho the blade remnants precluded isolation of the initiator blade. The blade material had satisfied specification requirements and no manufacturing or processing defects were detected.

4.2 The microstructure of a representative blade indicated exposure to above normal operating temperature. This observation seems to be supported by the available data from the engine condition trend monitoring which tracked a 20° C rise in ITT during the last few months prior to the incident.

4.3 The physical evidence consisting of pronounced rotational and circumferential damage to the right hand engine components leads to the conclusion that the engine was developing power at impact.

REFERENCES

1. Pratt & Whitney Canada Report No. 01-119, February 14, 2003

2. Hartzell Propeller Inc. Aircraft Accident/Incident Report No. 011127, January 6, 2003

Appendix C: LQH maintenance notification spreadsheet

MAINTENANCE NOTIFICATION
JOB No:

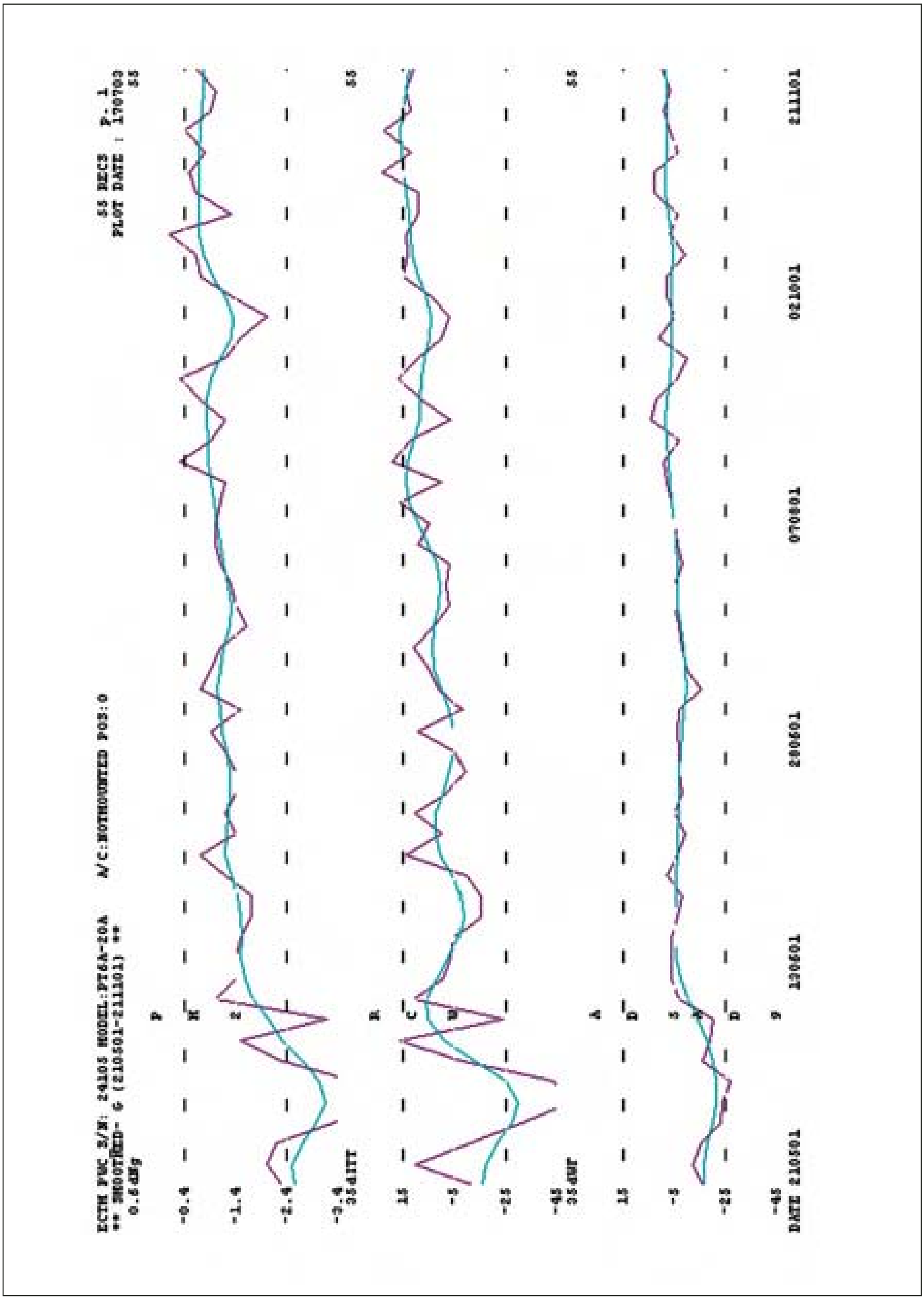
VH-LQH
BEECHCRAFT C90
S/N LJ-644

Please return on completion of tasks
Maintenance carried out as detailed
Sig: ....Lic:.........
Maintenance Co-ord

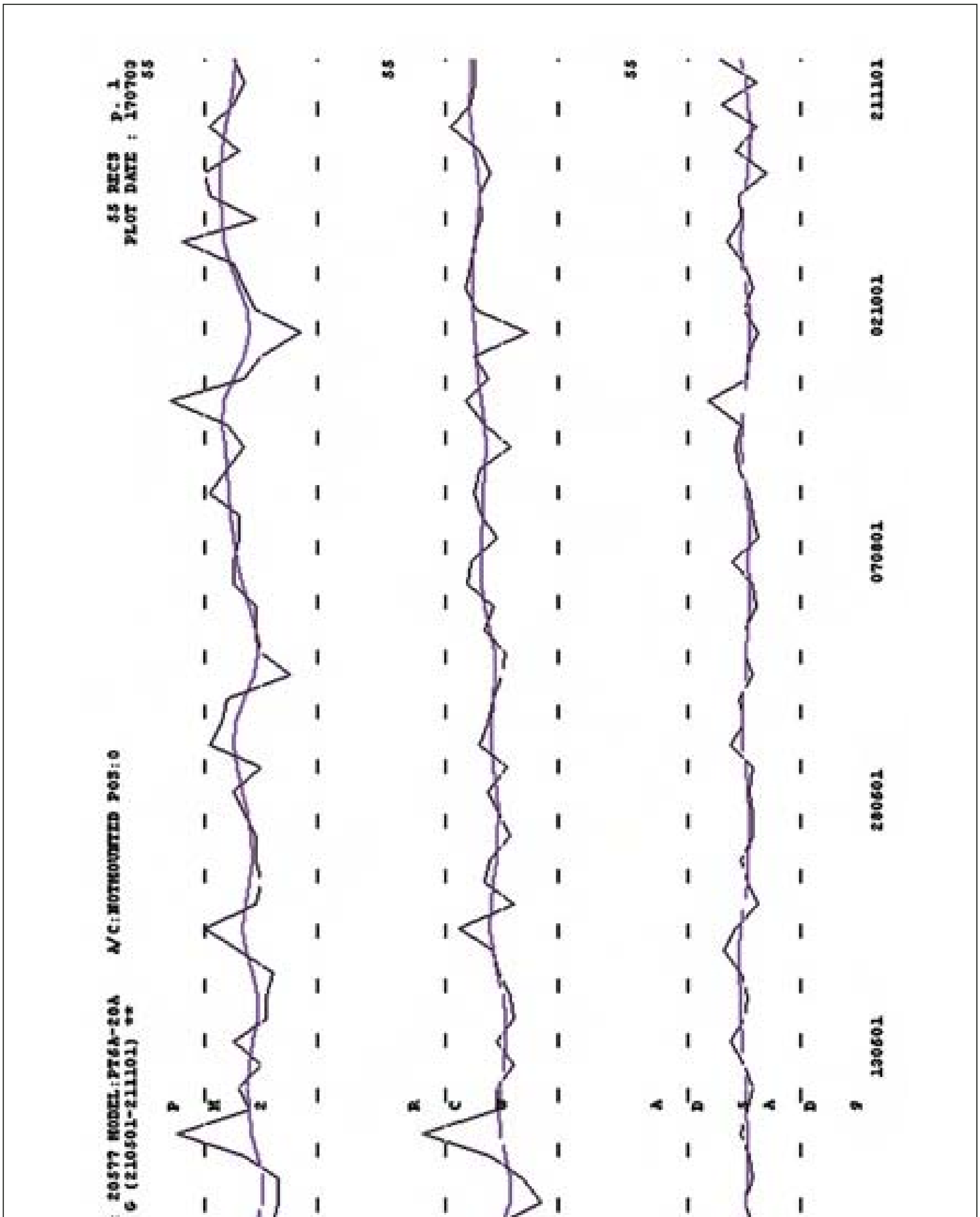
ATA	Maintenance Item	Loc	Description	Part No.	Serial No.	TSN/TSO @ Install	PCW Date	PCW Hours	PCW Ldgs	Interval	T	Next Due	TSN/TSO	TTR	Remarks	To be carried out	Carried out (initial)
5	Maintenance Release				A0057		7-Jun-01	6772.2	7043	220.0	H	6992.2	158.4	61.6			
99	AD/BEECH 90/78 Amdt 2		Rudder Pedal Arms				13-Dec-00	6565.9		12	M	13-Dec-01	355	10			
99	AD/ENG/5 Amdt 7		Para 2.6 (a)	Engine Overhaul	See Above									99999	Refer ATA 72		
99	AD/ENG/5 Amdt 7		Appendix A, para 3	Hot Section Inspection	See Above									99999	Refer ATA 72		
99	AD/ENG/5 Amdt 7		Appendix A, para 3	Hot Section Borescope	See Above									99999	Refer ATA 72		
99	AD/ENG/5 Amdt 7		Appendix A, para 4	Fuel Nozzles	See Above					460				99999	Refer ATA 73		
99	AD/ENG/5 Amdt 7	L	Appendix A, para 5	Oil Filter Inspection				6772.2		220	H	6992.2	158	61.6			
99	AD/ENG/5 Amdt 7	L	Appendix A para 6	Reduction G'box Chip Detector			7-Jun-01	6772.2		220	H	6992.2	158	61.6			
99	AD/ENG/5 Amdt 7	R	Appendix A, para 6	Reduction G'box Chip Detector			7-Jun-01	6772.2		220	H	6992.2	158	61.6			
99	AD/ENG/5 Amdt 7		Appendix A para 8	1st Stage Compressor			7-Jun-01	6772.2		220	H	6992.2	158	61.6			
99	AD/ENG/5 Amdt 7		Para 2.6 (b) (viii)	Compressor Power Recovery				6772.2		220	H	6992.2	158	61.6			
99	AD/ENG/5 Amdt 7		Para 2.6 (b) (viii)	Compressor Power Recovery			27-Sep-01			3	M	27-Dec-01	67	24			
99	AD/ENG/5 Amdt 7		Para 2.6 (b) (ix)	Planet Gear Bearings										99999	Refer ATA 72		

Appendix D: LQH ECTM data graphs

Left engine ECTM data graph



Right engine ECTM data graph



Appendix E: *Safe operation of light twins,* Aviation Safety Digest

The following extract is from the Bureau of Air Safety Investigation, Aviation Safety Digest No.125, Winter 1985 edition.

Safe operation of light twins

Accidents involving light twin-engine aircraft in Australia continue to indicate that not all pilots understand as well as they should all of the basic factors involved in operating a twin.

This photograph by Mr Brenton Hollitt was a highly commended entry in the BASI Photographic Competition. Mr Hollitt used a Pentax SP 1000 with Kodak C135 100 ASA film.

The major demand in flying a twin as opposed to a single is knowing how to manage the flight if one engine loses power for any reason. This may sound obvious, but experience unfortunately indicates that it is not. Safe flight with one engine-out requires proficiency in two areas:

- an understanding of the factors affecting aircraft performance during asymmetric flight; and
- piloting competence in inflight engine-out procedures.

These key factors are discussed below in relation to climb performance and controllability.

Climb performance

Climb performance depends on an excess of power over that required for level flight. Loss of power from one engine obviously represents a 50 per cent loss of power, but *in virtually all light twins, climb performance is reduced by at least 80 per cent* (see Figure 1).

The amount of power required for level flight depends on how much drag must be 'overcome' to sustain level flight. It is obvious that, if drag is increased because the gear and flaps are down and the propeller is windmilling, more power will be required. Not so obvious, however, is the fact that drag also increases as the square of the airspeed, while power required to maintain that speed increases as the cube of the airspeed (see Figure 2).

Figure 1. Effect of one engine-out and aircraft configuration on vertical speed.

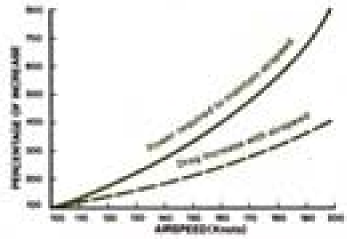


Figure 2. Effect of airspeed on drag—and power required to maintain that airspeed while in level flight.

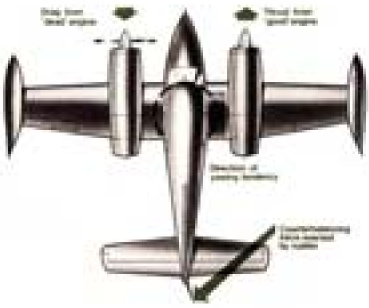


Figure 3. Yaw

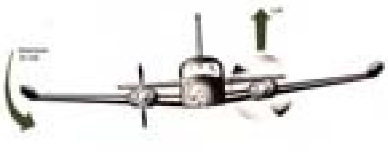


Figure 4. Roll

Figure 5. Engine thrust line shifts to right at low airspeeds and at high angles of attack

Thus, climb performance depends on four factors:

- **Airspeed**—too little or too much will decrease climb performance.
- **Drag**—gear, flaps, cowl flaps, propeller, speed and slip angle.
- **Power**—amount available in excess of that needed for level flight.
- **Weight**—passengers, baggage and fuel load greatly affect climb performance.

Controllability

Aerodynamic controllability can be considered initially in terms of yaw and roll.

Yaw. Loss of power on one engine creates yaw towards the failed engine. Yaw forces must be balanced with the rudder (see Figure 3).

Roll. Loss of power on one engine reduces propeller wash over that wing. Yaw also affects the lift distribution over that wing: in combination, these factors cause a roll towards the 'dead' engine (see Figure 4). The roll forces may be balanced with use of opposite aileron. It is also most important to note that total aircraft drag, and rudder force, are decreased by banking the aircraft towards the 'live' engine. This will, for a steady heading, result in an unbalanced skid ball, but this, and the minor disadvantage of slightly increased aileron forces, greatly outweigh higher rudder forces and extra airframe drag caused by the greater sideslip which occurs with the wings level attitude.

Note that airspeed control and the power set on the live engine are also critical as far as controllability is concerned; these factors are discussed later in this article.

Critical engine

The critical engine is that engine which, if it fails, will most adversely affect the performance or handling qualities of the aircraft. The critical engine on most U.S.-built light twins—i.e., the majority of those flying in Australia—is the left engine, as its failure requires the most rudder force to overcome yaw. The reason for this is as follows. At cruise speeds and power settings, the thrust line of each engine acts through the propeller hub; thus, neither engine is particularly critical. However, at low airspeeds and high angles of attack, the effective thrust centreline shifts to the right on each engine because the descending propeller blades produce more thrust than the ascending blades (this is known as the P-factor). Thus, the right engine produces a greater mechanical yawing moment than does the left, and so requires a greater rudder force to counteract that yaw (see Figure 5).

Airspeed control

Airspeed control is the key to safe single-engine operations. Certain speeds must be known and understood by twin pilots. This article discusses those speeds in two sections:

- Immediately below, the practical implications of those speeds are defined.
- In the subsequent section, a more detailed discussion is provided, first, of the conditions under which the speeds are determined and, second, of significant operating considerations related to critical speeds.

Key airspeeds

- **Vmca** – the airspeed below which control of the aircraft will probably be lost.
- **Vsse** – the intentional one-engine inoperative speed is a minimum speed selected by the manufacturer for intentionally rendering one engine inoperative in flight for training purposes.
- **Vyse** – the airspeed that will give the best single-engine rate-of-climb (or the slowest loss of altitude).
- **Vxse** – the airspeed that will give the steepest angle-of-climb with one engine-out.

These key airspeeds are depicted graphically at Figure 6.

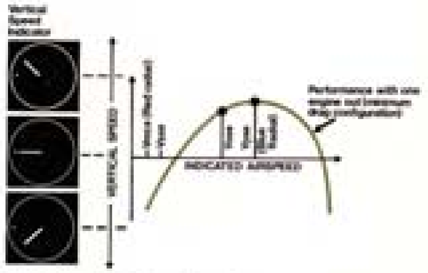


Figure 6. Key single engine airspeeds.

Minimum control airspeed

Vmca is designated by the red radial on the airspeed indicator and defines minimum control speed, airborne, at sea level. It is determined by the manufacturer as the minimum airspeed at which it is possible to recover control of the aircraft within 20 degrees of heading change, and thereafter maintain straight flight with not more than 5 degrees of bank if one engine fails *suddenly* with:

- takeoff power set on both engines;
- the rearmost allowable centre of gravity;
- flaps in the takeoff position;
- landing gear retracted; and
- the propeller of the failed engine in the takeoff pitch position (or feathered if fitted with auto-feather).

Sudden engine failures rarely occur with all of the factors listed above, so the actual Vmca in a particular situation may be a little lower than that indicated on the ASI. On the other hand, most light twins will not maintain level flight at an airspeed at or near Vmca; consequently, it is not advisable to fly at speeds approaching Vmca except during training or test flights.

It should be remembered that to minimise the difficulties which occur on *sudden* failure under the critical circumstance (e.g. just after takeoff), the pilot should accelerate quickly to recommended single engine and then all-engines operating climb speeds. It is important also to remember that whilst some manufacturers provide a speed margin between Vmca and recommended lift-off speed, others do not, and there may be very little or no speed margin provided in the data, for either reasons of ground control or merely the desire of the manufacturer to show minimal takeoff distance figures.

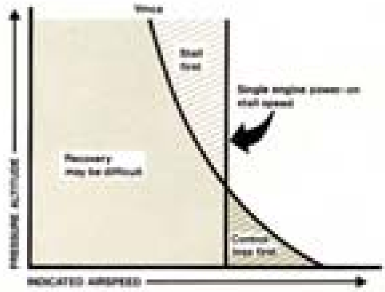


Figure 7. Relationship between stall speed and Vmca for aircraft with normally aspirated engines.

Vsse and Vmca demonstrations

Vsse may be specified by the aeroplane manufacturer in Pilot's Operating Handbooks, and is the minimum speed at which an engine should be deliberately shut-down for training or demonstration purposes. The use of Vsse is intended to reduce the accident potential from loss of control after an engine shut-down at or near minimum control speed. Vmca demonstrations are necessary in training but must not be practised with a propeller feathered or an engine shut down. In addition, the pilot-in-command must ensure that:

- the aircraft is at a safe altitude above the terrain, and
- Vmca for the particular aircraft type is greater than the stall speed for the configuration and weight.

To demonstrate this sequence, power reduction should be made on one engine at or above Vsse or, where Vsse is not specified, at a safe margin above Vmca. Power on the operating (good) engine should be set at the position for maximum continuous operation. Airspeed is then reduced slowly (one knot per second) until control of the aircraft can no longer be maintained (e.g. heading cannot be maintained through loss of directional control, or lateral control cannot be maintained; the limits may be dictated by control forces or control stops). Note that at higher altitudes, with normally aspirated engines, the first symptoms of a stall may appear before Vmca is reached (see Figure 7). Recovery is necessary so that spin conditions are avoided. This exercise, which in fact is the determination of *static* Vmca at the particular altitude under the given conditions, should precede *dynamic* Vmca exercises, where simulated *sudden* engine failures (as opposed to the preset reduced power settings used for static Vmca demonstrations as described above) are made in the appropriate configuration at decreasing airspeeds.

Recovery from flight below Vmca is made by reducing power on the operating (good) engine, decreasing the angle of attack by lowering the nose, accelerating through Vmca, and then restoring required power to the operating engine and accelerating to Vyse, the blue radial speed.

Best single-engine rate-of-climb speed

Vyse is designated by the blue radial on the airspeed indicator. Vyse delivers the greatest gain in altitude in the shortest possible time, and is based on the following criteria:

- critical engine inoperative, and its propeller in the minimum drag position;
- operating engine set at not more than maximum continuous power;
- landing gear retracted;
- wing flaps in the most favourable (i.e., best lift/drag ratio) position;
- cowl flaps as required for engine cooling; and
- aircraft flown at the recommended bank angle.

Drag caused by a windmilling propeller, extended landing gear, or flaps in the landing position, will severely degrade or destroy single-engine climb performance. Single-engine climb performance varies widely with the type of aircraft, weight, temperature, altitude and aircraft configuration. The climb gradient (altitude gain or loss per mile) may be marginal or even negative under some conditions. Study the Pilot's Operating Handbook for your specific aircraft and know what performance to expect with one engine out.

Best single-engine angle-of-climb airspeed

Vxse is used only to clear obstructions during an initial climb-out as it gives the greatest altitude gain per unit of horizontal distance. It provides less engine cooling and requires more rudder deflection than Vyse.

General considerations

Having discussed the main aspects of key single-engine performance speeds, attention must now be drawn to some important general operational considerations.

Single-engine service ceiling

The single-engine service ceiling is the maximum altitude at which an aircraft will climb, at a rate of at least 50 feet per minute in smooth air, with one propeller feathered.

The single-engine service ceiling chart should be used during flight planning to determine whether the aircraft, as loaded, can maintain the en route lowest safe altitude if IFR, or terrain clearance if VFR, following an engine failure.

Basic single-engine procedures

Know and follow the single-engine emergency procedures specified in your Pilot's Operating Handbook for your specific make and model of aircraft. The following procedures apply generally:

- Maintain aircraft control and airspeed at all times. This is cardinal rule no: 1.
- Usually, apply maximum power to the operating engine. However, if the engine failure occurs during cruise or in a steep turn, you may elect to use only enough power to maintain a safe speed and altitude. If the failure occurs on final approach, use power only as necessary to complete the landing.
- Reduce drag to an absolute minimum.
- Secure the failed engine and related sub-systems.

The first three steps should be done promptly and from memory. The check list should then be consulted to be sure that the inoperative engine is secured properly and that the appropriate switches are placed in the correct position.

CAUTION: *Be sure to identify the dead engine positively before feathering its propeller.* Many pilots – both students and veterans alike – have feathered the wrong propeller. Do not let it happen to you. Remember, first identify the suspect engine ('dead leg, dead engine'); second, verify your identification by cross-reference to engine instruments and, on some piston engine aircraft, by cautious throttle movement; *then* feather. But be certain that the engine is dead and not just sick.

Engine failure on takeoff

If an engine fails before liftoff speed is attained, the only proper action is to discontinue the takeoff. If the engine fails after liftoff with the landing gear still down, the takeoff should still be discontinued if touch down and roll-out on the remaining runway is still possible.

If you do find yourself in a position of not being able to climb, it is much better to pull the power on the good engine and land straight ahead than to try to force a climb and lose control.

Pilot's Operating Handbooks for a number of light twins contain guidance concerning engine failure during takeoff, specifically in relation to:

- **Accelerate–stop distance:** this is the distance required to accelerate to liftoff speed and, assuming an engine failure at the instant that liftoff speed is attained, to bring the aircraft to a full stop.
- **Accelerate–go distance:** this is the distance required to accelerate to liftoff speed and, assuming an engine failure at the instant liftoff speed is attained, to continue the takeoff on the remaining engine to a height of 50 feet.

When considering such guidance, pilots should make allowance, not only for the prevailing conditions, but also for the fact that the manufacturer's data may have been determined under favourable test conditions.

Study your accelerate–go charts carefully. Most aircraft are not capable of climbing out on one engine under all weight, pressure altitude and temperature conditions. Know, before you taxi, whether you can maintain control and climb-out if you lose an engine while the gear is still down. It may be necessary to off-load some weight, or wait for more favourable temperature or wind conditions.

It is important to realise that there is no regulatory requirement for continued takeoff capability in light twin aircraft, *nor the requirement for any positive climb at all* in certain small light twins. There is much truth in the somewhat cynical statement that 'many light twin-engine aircraft are merely single-engine aircraft with their power divided into two individual packages'. The capability of en route continuation of flight and safe landing after an engine failure is usually there; however, the capability of some light twins for climbing away from the ground after sudden engine failure, even if the optimum configuration is quickly achieved and faultless pilot performance exhibited, is often just not available.

When to fly Vx, Vy, Vxse and Vyse

During normal two-engine operations, always fly Vy (or Vx if necessary for obstacle clearance) on initial climb-out. Then, accelerate to your cruise climb airspeed, which may be Vy plus 10–15 knots after you have obtained a safe altitude. Use of cruise climb airspeed will give you better engine cooling, increased inflight visibility and better fuel economy. However, at the first indication of an engine failure during climb-out, or while on approach, establish Vyse or Vxse, whichever is appropriate. (Consult your Handbook or Flight Manual for specifics.)

Remember, too, that single-engine go-arounds in light twins are virtually impossible unless they are commenced several hundred feet above the ground and with adequate airspeed in hand. Plan any single-engine approach well ahead, use final flap with extreme caution and only when committed and keep that airspeed up, again until committed.

Summary

Know the key airspeeds for your aircraft and when to use them:

Vmca (Red radial)—never fly at or near this airspeed except in training or during flight tests.

Vsse—never intentionally shut down an engine below this airspeed.

Vyse (Blue radial)—always fly this airspeed during a single-engine emergency during climb-out (except when necessary to clear an obstacle after takeoff) and on final approach until committed for landing.

Vxse–fly Vxse to clear obstacles, then accelerate to Vyse.

Know the performance limitations of your aircraft, including its:

- accelerate–stop distances;
- accelerate–go distances;
- single-engine service ceiling; and
- maximum weight at which a single-engine climb is possible.

Know the basic single engine emergency procedures:

- Maintain control of the aircraft by flying at the proper airspeed.
- Apply maximum power, if appropriate.
- Reduce drag (includes feathering).
- Complete engine-out checklist.

And finally, put your knowledge into practice with a qualified instructor observing and assisting you. Engine failure can be handled competently and safely by proficient pilots. Proficiency is related to currency, and both are fundamental to safety. ●

F: Extracts from FAA-H-8083-3 *Airplane Handbook*

The following extracts are from the Federal Aviation Administration FAA-H-8083-3 Airplane Handbook.

CHAPTER 14
TRANSITION TO A MULTIENGINE AIRPLANE

NORMAL TAKEOFFS

In the interest of safety, it is important that the pilot have a plan of action to cope with engine failure during takeoff. In a multi-pilot crew, the flying pilot should brief the crew on his or her plan of action for normal and abnormal procedures and their individual responsibilities. This briefing consists of at least the following: minimum control speed (VMC), rotation speed (VR), lift-off speed (VLOF), single-engine best rate-of-climb speed (VYSE), all-engine best rate-of-climb speed (VY), and what procedures will be followed if an engine failure occurs prior to VMC and after VMC. The multiengine pilot's primary concern on all takeoffs is the attainment of the single-engine minimum control speed plus 5 knots prior to lift-off. Until this speed is achieved, directional control of the airplane in flight may be impossible after the failure of an engine, unless power is reduced immediately on the operating engine. If an engine fails before the single-engine minimum control speed is attained, THE PILOT HAS NO CHOICE BUT TO CLOSE BOTH THROTTLES, ABANDON THE TAKEOFF, AND DIRECT COMPLETE ATTENTION TO BRINGING THE AIRPLANE TO A SAFE STOP ON THE GROUND.

The multiengine pilot's second concern on takeoff is the attainment of the best rate-of-climb speed (VY) in the least amount of time. This is the airspeed that will provide the greatest rate of climb with both engines operating. In the event of an engine failure, the single-engine best rate-of-climb speed must be held. This will provide the best rate of climb when operating with one engine inoperative and propeller feathered (if possible), or the slowest rate of descent with the proper bank angle toward the operating engine. When takeoff is made over obstructions, the best angle-of-climb speed should be maintained until the obstacles are passed then the best rate of climb maintained.

ENGINE FAILURE BEFORE LIFT-OFF (REJECTED TAKEOFF)

When an engine fails during the takeoff roll before becoming airborne, it is advisable to close both throttles immediately and employ maximum braking, while maintaining directional control.

ENGINE FAILURE AFTER LIFT-OFF

If after becoming airborne an engine should fail prior to having reached the single-engine best rate-of-climb speed (VYSE), the same procedure used for engine failure before lift-off should be followed. This is recommended because an immediate landing is usually inevitable because of the altitude loss required to increase the speed to VYSE.

The pilot must have determined before takeoff what altitude, airspeed, and airplane configuration must exist to permit the flight to continue in the event of an engine failure. The pilot should also be ready to accept the fact that if engine failure occurs before these required factors are established, both throttles must be closed and the situation treated the same as an engine failure on a single-engine airplane. If it has been predetermined that the single-engine rate of climb under existing circumstances will be at least 50 FPM at 1,000 feet above the airport, and that at least the single-engine best angle-of-climb speed has been attained, the pilot may decide to continue the takeoff. If the airspeed is below the single-engine best angle-of-climb speed (VXSE) and the landing gear has not been retracted, the takeoff should be abandoned immediately.

When the decision is made to continue the flight, the single-engine best rate-of-climb speed should be attained and maintained with the inoperative engine feathered. Even if altitude cannot be maintained, it is best to continue to hold that speed because it would result in the slowest rate of descent and provide the most time for executing the emergency landing. After the decision is made to continue flight and a positive rate of climb is attained, the landing gear should be retracted as soon as practical.

The best way to identify the inoperative engine is to note the direction of yaw and the rudder pressure required to maintain heading. To counteract the asymmetrical thrust, extra rudder pressure will have to be exerted on the operating engine side. To aid in identifying the failed engine, some pilots use the expression “Dead Foot Dead Engine.”

Experience has shown that the biggest problem is not in identifying the inoperative engine, but rather in the pilot’s actions after the inoperative engine has been identified. In other words, a pilot may identify the inoperative engine and then attempt to shut down the wrong one, resulting in no power at all. To avoid this mistake, the pilot should verify that the inoperative engine has been identified by retarding the throttle of the suspected engine before shutting it down [this action would not be appropriate in a C90 aircraft that is fitted with a propeller automatic feathering system].

Appendix G: Factors that can influence pilot's response time

Response time consists of two main parts: 'reaction time', or the time from the onset of the problem (or stimuli) until the pilot starts a response; and 'movement time', or the time to actually conduct the response movement.[60] The reaction time component involves the processes of detecting the stimuli, recognising that there is a problem, identifying the nature of the problem, and then deciding on an appropriate type of response.

Response time for a simple task in laboratory situations can be as low as 150-200 milliseconds. In real world setting, however, response times are much longer due to a variety of factors.[61] For example:

- Response time generally increases as the person's expectation that the stimuli will occur decreases. Rare events, such as engine failures, will usually not be expected to occur. This is why it is generally recommended that pilots conduct a pre-takeoff self briefing which includes deciding what to do if there is an engine failure (see Section 1.20.7).
- Response time generally increases as the salience of the stimuli decreases. For example, while some engine problems are easy to detect, others may be more subtle, and it is not always easy to diagnose the nature of the problem or which engine is producing the problem.
- Response time generally increases as the number of possible stimuli and the number of possible responses to the stimuli increases. During the take-off roll, there are many potential problems that may confront a pilot in addition to an engine failure.
- Response time generally increases as the opportunity to practice the response decreases. As noted in Section 1.20.9, pilots flying general aviation aircraft on charter flights have few opportunities to practice responses to engine failures late in the take-off roll or immediately after the aircraft becomes airborne.
- Response time generally increases as workload increases. Takeoff is a high workload phase of flight.
- Response time generally increases as the complexity of the required response increases. Complexity of response refers to the difficulty of particular movements, as well as the number of different required movements. As discussed in Section 1.20.8, the response to an engine failure in a multi-engine aircraft requires a number of actions.
- Response time generally increases as fatigue and other general physiological problems increase.

Exactly how long a pilot's reaction time will be in any particular situation is difficult to estimate due to the large number of factors involved. Steenblik reported information from a number of runway overrun accidents involving high capacity jet aircraft in which pilots rejected the takeoff in response to some form of emergency event during the take-off roll.[62] Based on flight data recorder and cockpit voice recorder information provided in the final investigation reports for seven of the accidents, the time to complete the first pilot action in response to the event ranged

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60 Many publications use the term "reaction time" instead of "response time" to refer to the total time it takes to complete a response to the relevant stimuli.

61 Sanders, M. S. & McCormick, E. J. *Human Factors in Engineering and Design* (7th edition), New York, McGraw-Hill., 1992, pp.285-293.

62 Steenblik, J. W., 'RTO reaction times in the real world, Part II', *Air Line Pilot*, May 1994, pp.30-34.

from 1.0 seconds to 4.0 seconds, with most responses in the range of 1.0 to 2.0 seconds. Such situations usually require the completion of at least three pilot actions, such as closing the thrust levers, applying manual braking, and deploying the thrust reversers. To complete all of the actions requires additional time.

A recent study by Harris and Khan examined the response times of professional pilots to reject a takeoff in a transport aircraft simulator following an 'abort' call by another pilot.[63] The aircraft's speed at the time of the 'abort' call was varied. The time to make the first pilot action to reject the takeoff in response to the abort call was about 2 seconds when the speed was well below V_1.[64] As speed on the runway increased, response times to an abort call decreased to about 1 second at a point just before V_1. Response times then increased dramatically to about 2 seconds when the abort call was made at V_1. The standard deviation of responses was about 0.5 second when the speed was well below V_1, but increased to about 1.0 second at about V_1.

The authors noted that this pattern of results was similar to that found in previous road safety research examining decision times to make an overtaking manoeuvre, with the decision times increasing at the 'overtaking threshold' (or the point where 50% of drivers elected to overtake and 50% did not).

It should be noted that in Harris and Kahn's study, the pilots had a high level of expectancy that they would be receiving an abort call during the takeoff. It should also be noted that, even though they were presented with the same situation, three of the 14 pilots who were presented with an abort call at 6 kts below V_1 elected to take off, and five of the 16 pilots who were presented with an abort call at V_1 elected to take off. In the latter case, by the time that the pilots looked at the speed to make the decision as to whether to take off or not, the speed was probably in excess of V_1.

Research conducted for the UK Civil Aviation Authority examined professional pilots' response times to total engine failures in three types of helicopters during simulator training flights.[65] The mean response times were 2.3 seconds (Chinook), 3.3 seconds (S-61N), and 4.1 seconds (Super Puma). The 90th percentile response times were 4.4, 5.7 and 4.7 seconds respectively.

To meet airworthiness standards, aircraft manufacturers are required to allow for the pilot response time to an engine failure when calculating the accelerate-stop distance. The current requirements in this area for aircraft in the normal category were outlined in FAR Part 23. The FAA Advisory Circular 23-8B stated that an acceptable means of compliance with the regulatory requirements was to consider the demonstrated time to make the first pilot action (or 1 second, whichever was greater) to reject a takeoff[66], the demonstrated time to make the second pilot action plus 1 second to allow for in-service variations, and the demonstrated time to make the third pilot action plus 1 second to allow for in-service variations[67]. The Accelerate-Stop Distance (Flaps 0%) chart contained in the aircraft manufacturer's *King Air C90 Pilot's Operating Manual* stated that 'distances included a 3-second recognition time'.

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63 Harris, D., & Khan, H., 'Response time to reject a takeoff', *Human Factors and Aerospace Safety*, vol. 3, 2003, pp. 165-175.

64 V_1 is the speed in a multi-engine aircraft at which, if an engine fails, the remaining runway will allow either a deceleration to a full stop, or a takeoff to a specified height. V_1 is generally only used for aircraft certificated in the transport category and high performance aircraft.

65 Flight Safety Foundation , 'Simulator-based study of emergencies yields insights into pilots' reaction times', *Helicopter Safety*, vol. 25, 1999, pp. 1-5.

66 The demonstrated time from engine failure to the first pilot action was termed the 'engine failure recognition time'.

67 The current requirements for considering pilot response time for the accelerate-stop distance in transport aircraft were outlined in the FAA AC 25-7A.

Appendix H: Inappropriate pilot responses to engine failures

H.1 Overseas research

Following an accident in the US in December 1994, the US Federal Aviation Administration (FAA) requested the Aviation Industries Association (AIA) to conduct a review of serious incidents and accidents that involved an engine failure or perceived engine failure and an 'inappropriate' crew response. The AIA conducted the review in association with the European Association of Aerospace Industries (AECMA) and produced their report in November 1998.

The review examined all accidents and serious incidents worldwide which involved 'Propulsion System Malfunction + Inappropriate Crew Response (PSM+ICR)'. Those events were defined as 'where the pilot(s) did not appropriately handle a single benign engine or propulsion system malfunction. Inappropriate responses included incorrect response, lack of response, or unexpected and unanticipated response'. The review focussed on events involving western-built commercial turbofan (jet) and turboprop aircraft in the transport category. The review conclusions included the following:

- The rate of occurrences per airplane departure for PSM+ICR accidents has remained essentially constant for many years. Those types of accidents are still occurring despite the significant improvement in propulsion system reliability that has occurred over the past 20 years, suggesting that the rate of inappropriate crew response to propulsion system malfunction rates has increased.
- As of 1998, the number of accidents involving PSM+ICR was about three per year in revenue service flights, with an additional two per year associated with flight crew training of simulated engine-out conditions.
- Although the vast majority of propulsion system malfunctions are recognised and handled appropriately, there is sufficient evidence to suggest that many pilots have difficulty identifying certain propulsion system malfunctions and reacting appropriately.
- In the turboprop area particularly, pilots are failing to properly control the airplane after a propulsion system malfunction that should have been within their capabilities to handle.
- The research team was unable to find any adequate training materials on the subject of modern propulsion system malfunction recognition.
- There are no existing regulatory requirements to train pilots on propulsion system malfunction recognition.
- While current training programs concentrate appropriately on pilot handling of engine failure (single engine loss of thrust and resulting thrust asymmetry) at the most critical point in flight, they do not address the malfunction characteristics (auditory and visual cues) most likely to result in inappropriate response.

About half of the accidents involving turboprop aircraft in the transport category occurred during the take-off phase of flight. About 63% of the accidents involved a loss of control, with most of those occurring following the propulsion system malfunction during takeoff. There was only one accident involving a rejected takeoff, whereas just under half the accidents involving turbofan (jet) aircraft were runway overruns following a rejected takeoff.

The report made a number of recommendations to improve pilot training.

H.2 Accidents involving propulsion problems during takeoff in Australia

The investigation conducted a review of accidents that resulted from an engine problem (or perceived engine problem) in a multi-engine aeroplane during the take-off roll or initial climb (less than 500 ft above ground level) in Australia between 1991 and 2002. There were 21 accidents, all involving twin-engine propeller driven aircraft.

One of the aircraft was a turboprop in the transport category (Fairchild Metro SA227 involved in a training accident). The C90 accident involving VH-LQH at Toowoomba was the only other accident involving a turboprop aircraft. One of the other accidents involved a Douglas DC-3, a twin piston-engine aircraft with a maximum take-off weight greater than 5,700 kg.

One of the accidents occurred during a low capacity regular public transport (RPT) flight, seven occurred during passenger charter flights, two occurred on cargo charter flights, five occurred on training flights (including the Metro accident involving an RPT operator), and the remaining six occurred on private flights. Five of the accidents resulted in fatalities (two on passenger charter flights, two on private flights, and one on a training flight), with a total of 15 fatalities. Another seven accidents resulted in serious injuries.

Three accidents involved simulated failures during training flights, three involved failures due to fuel quantity, two involved perceived rather than actual failures, five involved some form of technical failure, and on the other eight occasions the reason for the reported failure was not able to be determined.

Aside from the accident involving VH-LQH, those accidents included the following:

- One of the fatal accidents involved a Cessna 337 aircraft, which has an unconventional design with a front and a rear engine mounted on the fuselage. The rear engine was not operating during the takeoff, and the pilot subsequently lost control during the initial climb.
- Two non-fatal accidents were on training flights where the instructor pilot simulated an engine failure during the take-off roll before the decision speed. In one accident, the student pilot elected to rotate, and the instructor recovered the situation but there was a hard landing. In the other accident, the student did not detect the engine failure, and the aircraft veered off the runway.
- Three non-fatal accidents involved an engine failure occurred just prior to or during rotation. On two occasions the pilots rejected the takeoff. One aircraft overran the runway after the pilot applied excessive braking and the wheels skidded. In another accident, the aircraft became airborne, and the pilot then landed on the runway and ground looped the aircraft to prevent an overrun accident. The third accident occurred during the takeoff after a touch-and-go landing. The instructor pilot detected a problem late in the take-off roll and took over control and elected to continue with the takeoff in order to clear obstacles. However, the aircraft failed to obtain sufficient height to clear the obstacles.
- Two accidents involved both engines failing due to fuel starvation/exhaustion after the aircraft was airborne. One was a fatal accident where the pilot lost control of the aircraft. In the other accident (non-fatal), the instructor pilot conducted a forced landing.
- The remaining 12 accidents involved the (real or perceived) engine failure occurring after the aircraft was airborne. In 10 of the accidents, the pilots made a forced landing after they could not maintain altitude or climb (or on one occasion could not control the yaw). On the other two occasions, the pilots lost control after attempting to turn back to land on the runway. In seven of the accidents, the pilots made an undesirable response to the situation, including feathering the propeller on the wrong engine, not feathering the propeller, not raising the landing gear, inappropriate use of the ailerons, not flying the aircraft at the right speed, and attempting turns at low level in an inappropriate configuration.

Overall, of the 21 accidents, at least 14 involved an undesirable response from the pilot flying, although in four of these accidents the pilot flying was a student pilot. In two instances, there were insufficient details available to make a judgement about the appropriateness of the pilots' response.

There were a number of other occurrences where an engine failure occurred during the take-off roll, or initial climb, and an accident did not result. The investigation did not review those occurrences in detail. It would be inappropriate to make conclusions on the rate of engine failures which are responded to appropriately as it is possible that many that do not result in accidents are not reported.

Appendix I: Aircraft manufacturer's procedures for responding to an engine failure

The following excerpts were taken from the *Approved Flight Manual* for VH-LQH. The first excerpt contains operational speeds, including key speeds relevant for managing an engine failure. The second excerpt (on the next page) contains the manufacturer's specified procedures for responding to an engine failure during takeoff.

OPERATIONAL SPEEDS

Minimum Single Engine Control	90 knots
Single Engine Best Angle of Climb	96 knots
Single Engine Best Rate of Climb	107 knots
Two Engine Best Angle of Climb	101 knots
Two Engine Best Rate of Climb	111 knots
Turbulent Air Penetration Speed	161 knots
Maximum Demonstrated Crosswind	25 knots
Cruise Climb	
SL - 10,000 feet	149 knots
10,000 - 20,000 feet	129 knots
20,000 - 25,000 feet	119 knots
Above 25,000 feet	109 knots

SINGLE ENGINE PROCEDURES

ENGINE FAILURE DURING TAKE-OFF

1. Below Take-off Speed:
   a. Power - IDLE
   b. Brakes - AS REQUIRED

   If insufficient runway remains for stopping:

   c. Condition Levers - CUT-OFF
   d. Fuel Firewall Valves - CLOSED
   e. Electrical Power - OFF (Gang bar down)
   f. Boost Pumps - OFF

2. If aircraft is airborne, and conditions preclude an immediate landing:
   a. Power - MAXIMUM ALLOWABLE
   b. Propeller RPM - FULL INCREASE
   c. Airspeed - NORMAL TAKE-OFF SPEED OR ABOVE
   d. Landing Gear - UP
   e. Power Lever (Inoperative engine) - IDLE

CAUTION

If the autofeather system is being used, do not retard the failed engine power lever until the autofeather system has completely stopped propeller rotation. To do so will deactivate the autofeather circuit and prevent automatic feathering.

   f. Propeller (inoperative engine) - FEATHER
   g. Flaps - UP
   h. Airspeed - BEST RATE OF CLIMB SPEED
   i. Clean-up (inoperative engine)
      (1) Condition Lever - CUT-OFF
      (2) Bleed Air Valve - AS REQUIRED
      (3) Auto Ignition - OFF
      (4) Fuel Firewall Valve - CLOSED
      (5) Boost Pump - OFF
      (6) Fuel Transfer Pump - OFF
      (7) Crossfeed - CLOSED
      (8) Generator - OFF
      (9) Fuel Control Heat - OFF
      (10) Autofeather Switch - OFF
      (11) Propeller Synchrophaser - OFF
   j. Electrical Load - MONITOR

CAUTION

If smoke or fumes are entering the cabin from the failed engine, close the Bleed Air Valve.

Appendix J: Operator's procedures for responding to an engine failure

The following excerpts were taken from Part B of the operator's *Operations Manual* for the C90 aircraft. The first excerpt contains operational speeds, including key speeds relevant for managing an engine failure. The second excerpt (on the next page) contains the operator's specified procedures for responding to an engine failure during takeoff.

3.2.1. EMERGENCY AIRSPEEDS (4,377kgs)

One-Engine-inoperative Best Angle-of-Climb (V_x)	101kts
One-Engine-inoperative Best Rate-of-Climb (V_y)	108kts
Air Minimum Control Speed (V_{MCA})	90 kts
One-Engine-inoperative Enroute Climb	121kts
Emergency Descent	156kts
One-Engine-inoperative Landing:	
Approach (Flaps Approach)	113kts
When Landing Assured (Flaps Down)	103kts
Intentional One-Engine-inoperative Speed (V_{SSE})	97kts
Maximum Range Glide	125kts

3.2.3. **Engine Failure During Ground Roll**

a	Power Levers	- IDLE
b	Brakes	- AS REQUIRED
c	Operative Engine	- MAXIMUM REVERSE

Note:

ITEMS a, b, and c above should be actioned almost simultaneously

WARNING:

EXTREME CARE MUST BE EXERCISED WHEN USING SINGLE-ENGINE REVERSING ON SURFACES WITH REDUCED TRACTION.

If Insufficient Runway Remains for Stopping.

d	Condition Levers	- CUT OFF
e	Fuel Firewall Valves	- CLOSED
f	Master Switch	- OFF (Gang bar down)
g	Boost Pumps	- OFF

3.2.2.4. **Engine Failure After Lift-off (if conditions preclude an immediate landing)**

1.	Power	– MAXIMUM ALLOWABLE
2.	Propeller rpm	– FULL INCREASE
3.	Airspeed	– MAINTAIN (take-off speed or above)
4.	Landing Gear	– UP

NOTE: **If the autofeather system is being used, do not retard the failed engine power lever until the autofeather system has completely stopped propeller rotation. To do so will deactivate the autofeather circuit and prevent automatic feathering.**

5. Propeller (inoperative engines) - FEATHER

6. Airspeed - BEST RATE-OF-CLIMB SPEED (after obstacle clearance altitude is reached)
7. Flaps - UP
8. Clean-up (inoperative engine)
   a. Condition Lever - CUT-OFF
   b. Bleed Air Valves - AS REQUIRED
   c. Auto Ignition - OFF
   d. Fuel Firewall Valve - CLOSED
   e. Boost Pump - OFF
   f. Fuel Transfer Pump - OFF
   g. Crossfeed - CLOSED
   h. Generator - OFF
   i. Fuel Control Heat - OFF
   j. Autofeather - OFF
   k. Propeller Syncrophaser - OFF
9. Electrical Load - MONITOR

Appendix K: Article from CASA *Flight Safety Australia* Magazine

WHAT WENT WRONG?

Twin trouble

If your engine fails after take-off, should you close the throttles and land straight ahead or try to climb away?

Stephen A. Thompson

IN 30 YEARS of general aviation and airline flying, I had not experienced the slightest hint of an engine malfunction. Yet late one February afternoon in 1997, all my years of training for such an event were put to the test.

It had long been my conviction that the pre-take-off briefings given by some multi-engine pilots were unduly pessimistic and lacking in understanding of the purpose and capabilities of multi-engined aircraft.

I well remember hearing a pilot about to depart from Essendon's Runway 26 in a Beech Baron state that he would close the throttles and land straight ahead if the aircraft suffered an engine failure below 400ft AGL. This seemed an unnecessarily risky course of action. More than 2,000m of sealed runway is ample for such an aircraft to accelerate to best-single-engine-rate-of-climb speed (over the runway), thus placing the aircraft in a position where an engine failure can be managed while continuing the take-off, obstacles considered of course.

There are certainly times when a total engine failure necessitates closing the throttles and landing straight ahead, but one is in a far better position to do this if the aircraft wheels are on, or very close to, the runway. However, in most twins, it is quite possible to maintain V_{yse}, retract the gear and feather, with as little as 100ft between you and the runway.

The following incident illustrates these points.

The company that I was working for at the time, maintained an excellent standard in pilot training, as did TAA, a former employer, and it was through these agencies that I credit the happy outcome of what could easily have been a disaster at Gunpowder Aerodrome in north-west Queensland.

The aircraft, a Beechcraft C90 Kingair, was fitted with auto-feather, and I armed it prior to take-off as per normal procedures.

The airstrip was 1,300m long, of unimproved surface and 800ft above sea level. Because of rising terrain surrounding the strip, landings were only to be made on 27 and take-offs on 09.

As a normal climb out after take-off would clear all obstacles with both engines operating normally, I rotated at 104kt and retracted the gear at positive climb indication. Almost immediately the left propeller auto-feathered. I confirmed that the torque had fallen, carried out the phase-one actions and checked aircraft performance. Airspeed was 107kt and altitude was being maintained, but there was nothing in reserve to facilitate climb.

A quick glance up ahead at the rising terrain made me realise that the safest course of action was to manoeuvre for

landing on 27 if that was possible. The other option was a controlled crash into timbered slopes.

The next three minutes or so seemed like an eternity. Terrain and timber flashed past the windows as I extracted all the circling room that existed in that little basin without banking so steeply as to induce a stall. This was one occasion when the wisdom of that requirement for all aircraft to have a serviceable stall warning device fitted and operating on every flight was driven home to me. There was little time to consider the effect of the angle of bank in that situation and the intermittent sounding of the stall warning was a priceless benefit. Despite our periodic grumbling and some temptation to cut corners with equipment serviceability at times, the Civil Aviation Orders and Minimum Equipment List are worth their weight in gold.

On very short final there appeared some fat in the airspeed and I lowered approach flap and gear. A few seconds after lock-down I flared and landed. Reverse pitch on the good propeller was not much use due to the inducement of yaw, so medium level wheel braking was all that was left to stop with. Fortunately the touch-down was made with sufficient strip remaining.

Needless to say, my passengers (a doctor and nurse) and I were delighted to be back safely on terra firma. I was in no doubt as to the outcome if the aircraft had not had sufficient speed to maintain altitude and to manoeuvre at the time of engine failure.

My policy is therefore to remain on the runway until I reach single-engine-best-rate-of-climb speed unless obstacles dictate otherwise, in which case an engine failure would place us in the same situation as those in a single-engined aircraft – a forced landing.

ANALYSIS > WHAT WOULD YOU DO?

Staff writers

The most important task in any emergency is to "fly the aircraft". In the conditions, the pilot must have flown with considerable precision to manoeuvre the aircraft safely onto the ground, maintaining best-rate-of-climb speed and balanced flight in the process.

He had obviously pre-considered the engine failure case, and on this occasion had wisely decided that landing straight ahead was not a viable option while any better alternative existed. In this case, that alternative was to continue the take-off and manoeuvre for a landing on the reciprocal runway. He flew accordingly, and achieved a satisfactory outcome.

The pilot's phase one actions were the first critical step, designed not only to ensure maximum climb performance, but also to ensure that the engine had in fact failed. For example, a common reason for activation of autofeather on rotation, is an insufficiently tensioned power lever friction nut. This can allow the power lever to be retarded by acceleration and vibration when the pilot's right hand moves to the gear selector, to a point where the reduced torque is sensed as an engine failure, and autofeather is activated. (If the engine is still operating, immediate movement of the power lever to maximum power, the first item on the phase one checklist, restores power immediately, even if the propeller has stopped rotating.)

Checklist actions also include securing the shut-down engine which guarantees maximum available performance and (in this aircraft) silences the undercarriage warning so it cannot be confused with the stall warning (which has a similar sound) so the pilot can concentrate on accurate flying with reduced performance.

The C90's flight manual indicates that a single-engine-climb gradient of (about) three degrees should have been available under typical temperature conditions with such a light load. It's all too easy to be wise after the event, and the prevailing circumstances of terrain and weather may well have supported the pilot's decision.

However, if an aircraft can maintain terrain clearance while turning through more than 180 degrees in (presumably) low-level turbulence, might there not have been an equivalent or higher possibility of climbing straight ahead, turning only enough to avoid the higher terrain, and flying to a more welcoming airfield?

Whatever the answers to those questions, reviewing any such incident gives all pilots an opportunity to ask themselves: "Given the known conditions, would I have made the same decision? A better one? Or a worse one? What is my criteria for aborting or continuing a take-off? And: "How well equipped would I have been to consider all the options at a split-second's notice?"

Reviewing such issues at leisure, and debating them with your peers and mentors, may well benefit you one day when the chips are unexpectedly down.

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