Department of Transport and Regional Services

Australian Transport Safety Bureau

INVESTIGATION REPORT
200003771

Pilot and Passenger Incapacitation

Beech Super King Air 200 VH-SKC
Wernadinga Station, Qld
4 September 2000

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

Cover photo indicative of the aircraft type.

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

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INTRODUCTION

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

In terms of aviation, the ATSB, through the Director of Air Safety Investigation, 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 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.

The ATSB performs its aviation functions in accordance with the provisions of the *Air Navigation Act 1920*, Part 2A. Section 19CA of the Act states that the object of an investigation is 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. The Act does not impose on the Director of Air Safety Investigation any duty to investigate a particular accident, serious incident, incident, or safety deficiency, and the Director is not subject to any liability whatever should other priorities lead to a decision not to investigate.

It is not the object of an investigation 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.

EXECUTIVE SUMMARY

On 4 September 2000, a Beech Super King Air 200 aircraft, VH-SKC, departed Perth, Western Australia at 1009 UTC on a charter flight to Leonora with one pilot and seven passengers on board. Until 1032 the operation of the aircraft and the communications with the pilot appeared normal. However, shortly after the aircraft had climbed through its assigned altitude, the pilot's speech became significantly impaired and he appeared unable to respond to ATS instructions. Open microphone transmissions over the next 8-minutes revealed the progressive deterioration of the pilot towards unconsciousness and the absence of any sounds of passenger activity in the aircraft. No human response of any kind was detected for the remainder of the flight. Five hours after taking off from Perth, the aircraft impacted the ground near Burketown, Queensland, and was destroyed. There were no survivors.

The investigation found that the pilot was correctly licensed, had received the required training, and that there was no evidence to suggest that he was other than medically fit for the flight. The weather presented no hazard to the operation of the aircraft on its planned route. The aircraft's flightpath was consistent with the aircraft being controlled by the autopilot with no human intervention after the aircraft passed position DEBRA. After the aircraft climbed above the assigned altitude of FL250, the speech and breathing patterns of the pilot displayed changes that were consistent with hypoxia, but a rapid or explosive aircraft cabin depressurisation was unlikely to have occurred.

Testing revealed that Carbon Monoxide and Hydrogen Cyanide were highly unlikely to have been factors in the occurrence, and the absence of irritation in the airways of the occupants indicated that a fire in the cabin was also unlikely. The possibility of the pilot alone being incapacitated by a medical condition such as a stroke or heart attack would appear unlikely, given that there was no apparent activity or action by the other occupants of the aircraft for the duration of the flight.

The investigation concluded that while there are several possible reasons for the pilot and passengers being incapacitated, the incapacitation was probably a result of hypobaric hypoxia due to the aircraft being fully or partially unpressurised and their not receiving supplemental oxygen. Due to the extensive nature of the damage to the aircraft caused by the impact with the ground, and because no recording systems were installed in the aircraft (nor were they required to be), the investigation could not determine the reason for the aircraft being unpressurised, or why the pilot and passengers did not receive supplemental oxygen.

However, the investigation concluded that an aural warning for high cabin altitude, and setting visual and aural alerts to operate when the cabin pressure altitude exceeds 10,000 ft, may have prevented the accident.

1 FACTUAL INFORMATION

1.1 History of the flight

On 4 September 2000, a Beech Super King Air 200 aircraft, VH-SKC, departed Perth, Western Australia at 1009 UTC (1809 Western Standard Time) on a charter flight to Leonora, with one pilot and seven passengers on board. The passengers were employees of a mining company returning to duty at the mine. After takeoff, the aircraft tracked as instructed by the air traffic services (ATS) controller. At 1010, the pilot was cleared to climb to flight level (FL)130, an altitude of approximately 13,000 ft.

At 1015, as the aircraft climbed through 7,500 ft, the controller asked the pilot if the aircraft could reach FL160 by 36 NM from Perth. The pilot replied in the affirmative, and the controller cleared him to climb to FL250, the planned cruising level, with the requirement to reach FL160 by 36 NM from Perth.

At 1020, as the aircraft passed through FL156, the controller cleared the pilot to fly direct to position DEBRA, which was on the Cunderdin to Leonora track. The pilot correctly acknowledged the transmission, and flew the aircraft to DEBRA.

At about 1033, as the aircraft climbed through FL256, the controller requested the pilot to verify the aircraft's altitude. The pilot replied, "Sierra Kilo Charlie–um–standby."

The ATC radar display showed that the aircraft's altitude continued to increase.

Over the period from 1034 to 1043, eight open microphone transmissions were made from the aircraft, the longest being about 4 minutes. The ATS Automatic Voice Recorder (AVR) recording of those transmissions contained the following:

- one unintelligible syllable;
- sounds of a person breathing;
- two chime-like tones, similar to those generated by electronic devices; and
- background noise that was consistent with engine/propeller noise.

There were no detectable sounds on the recording that indicated passenger activity, such as moving, coughing or talking.

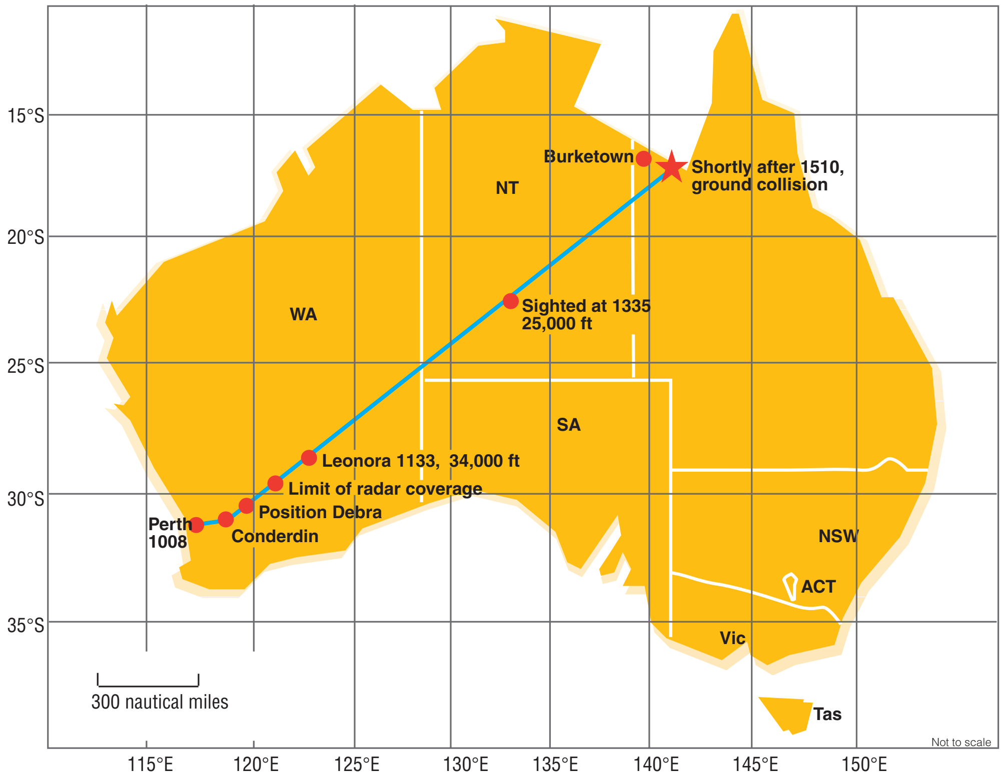
The pilot did not answer further radio transmissions made by the controller to the aircraft. Requests by the controller for the pilot to select the IDENT function on the aircraft's transponder ("squawk ident") and to change frequency did not produce any response. A transcript of communications between the controller and the pilot is contained in Attachment B.

The King Air continued to climb on the DEBRA to Leonora track and at 1102, the aircraft left radar coverage 218 NM (404 km) northeast of Perth while it was climbing through an altitude of FL325. At 1133, at the request of Australian Search and Rescue (AusSAR), the crew of a business jet aircraft flew near the King Air for a short period, while it was near Leonora. The jet crew reported that the King Air was maintaining FL343 on a steady heading of about 050°M. Although the King Air's external navigation and strobe lights were on, the jet crew saw no lights or movements inside the aircraft. The jet crew reported that the brightness of the strobe lights in the night conditions made it difficult to see inside the King Air.

At 1335, the King Air was sighted northwest of Alice Springs by the crews of two other aircraft that had been tasked to intercept and follow it. The King Air was passing FL250 in a steady descent, maintaining a heading of approximately 050˚M. The two chase aircraft remained with the King Air for the remainder of its flight. The crews reported that as the rate of the descent of the King Air slowly increased, its air speed increased to more than 200 kts. Although its external lights were on, nothing could be seen inside the cabin. The crews of the chase aircraft attempted to contact the pilot of the King Air by radio but they did not receive a response.

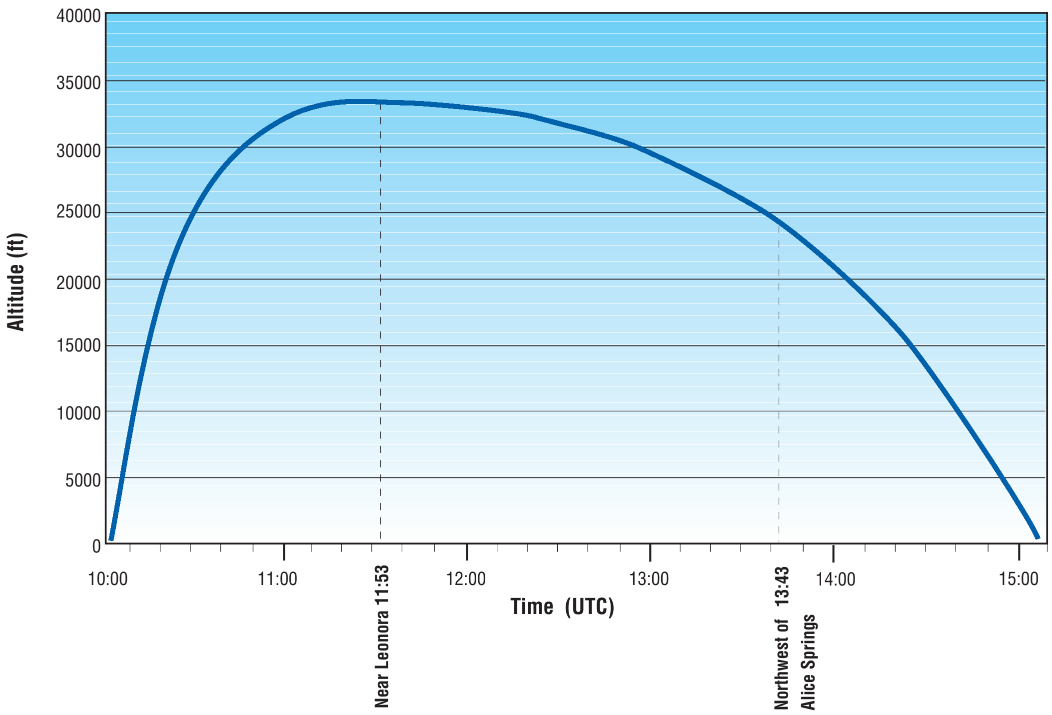
At 1510, the crew of one chase aircraft observed the King Air, at an altitude of less than 5,000 ft, turn left through 90˚. The King Air then impacted the ground and caught fire about 65 km southeast of Burketown. The aircraft disintegrated on impact. There were no survivors.

Figure 1:
Aircraft track VH-SKC 4 Sep 2000



The climb profile approximated a normal climb. The vertical profile flown by the aircraft and reports from the crews of the chase aircraft indicated that after reaching an altitude of FL343, the pitch attitude of the aircraft decreased over the next four hours, resulting in a slowly increasing rate of descent.

Figure 2:
Vertical flight profile of VH-SKC 4 Sep 2000



1.2 Injuries to persons

Degree of injury	*Crew*	*Passengers*	*Others*	*Total*
Fatal	1	7	-	8

1.3 Damage to aircraft

The aircraft was destroyed by the collision with the ground and the post-impact fire.

1.4 Other damage

No other property damage was reported.

1.5 Personnel information

1.5.1 Pilot in command

Personal details:	Male, age 50 years
Licence category:	Air Transport Pilot (Aeroplane) Licence
Medical certificate:	Class 1, Vision Correction required
Total hours:	2,053
Total hours on multi-engine aircraft:	1,401
Total hours on pressurised aircraft:	289
Total on type:	138
Total last 90 days:	52
Total last 90 days on type:	51

Total last 30 days:	19
Total last 24 hours:	0
Last check flight:	26 June 2000 (Instrument rating renewal test)
Last check flight on type:	18 July 2000 (Route check)

During January 2000, the pilot completed his Beech Super King Air 200 endorsement. The endorsement training included a simulated loss of cabin pressure.

It was reported that the pilot had a professional approach to flying and was methodical with his use of checklists. Witnesses reported that the pilot appeared happy and physically well before the flight. There was no evidence to suggest that the pilot was other than medically fit. There was also no evidence that fatigue was a factor in the occurrence.

1.5.2 Passenger information

The passenger who occupied the right pilot's seat had requested that seat so he could gain some familiarisation with commercial flying operations.

The seating positions of the remaining six passengers could not be determined.

1.6 Aircraft information

1.6.1 Aircraft data

Aircraft Manufacturer	Beechcraft Aircraft Corporation
Aircraft type	Super King Air 200
Aircraft Serial Number	BB-47
Aircraft Registration	VH-SKC
Year of Manufacture	1975
Aircraft Total Time in Service	18,771 hrs
Aircraft operational category stated on maintenance release	Charter, IFR

1.6.2 Engines and propellers

The aircraft had two Pratt and Whitney Canada PT6A-41 turbopropeller engines; each rated at 850 shaft horsepower. Each engine had an auto-ignition system that automatically provided an ignition source to the air-fuel mixture in the engine combustion chambers in the event of an engine flameout. The Beech Super King Air 200 FAA-Approved Airplane Flight Manual (AFM) required that the pilot arm the auto-ignition system before takeoff and disarm it after landing.

Each engine had a 3-bladed, full-feathering, constant-speed propeller. In the event of a loss of power from an engine, the propeller could be feathered either manually by the pilot selecting the feather position on the propeller lever, or automatically by the autofeather system. The AFM stated that the autofeather system was designed for use only during takeoff or landing. The Before Takeoff Checklist required the pilot to check and then arm the autofeather system. The Climb Checklist required the pilot to disarm the autofeather system.

1.6.3 Warning system

Civil Aviation Order (CAO) 108.26, Issue 1 (current at the time of the occurrence), Paragraph 3.1 stated:

> An oxygen system for an aircraft which is intended for operations at flight altitudes above 25,000 feet shall include a device to provide the flight crew with a warning whenever the cabin pressure altitude exceeds 10,000 feet.
>
> *Note:* The cabin pressure warning should not depend on the reading of the gauge. An aural warning is strongly recommended.

Occurrences ATSB 199902928 and ATSB 200105188, (see section 1.17), illustrated how pilots, occupied with other tasks, have missed visual warnings. Studies have shown that warning systems in complex domains such as aviation and medicine were made more effective by supplementing the systems' visual indications with aural warnings.[1]

1.6.3.1 Visual warning systems

A warning annunciator panel located in the cockpit contained ten red warning annunciator lights, which indicated faults that required immediate action by the pilot. The ALT WARN[2] annunciator illuminated whenever the cabin altitude exceeded 12,500 ft. The illumination of any red warning annunciator also triggered a red, flashing MASTER WARNING light on the glareshield in front of each pilot seat. The flashing MASTER WARNING light could be extinguished by pressing the lens cover on either of the lights. Extinguishing the MASTER WARNING flasher did not extinguish the warning annunciator that triggered it. Removing the condition or defect, which caused the annunciator to illuminate, was required.

The caution/advisory annunciator panel was at the bottom centre of the instrument panel. Caution lights (coloured yellow) indicated a fault that required the pilot's attention but not his immediate action. Advisory lights (coloured green) indicated functional situations of the aircraft systems and did not require pilot action. The illumination of any yellow caution light also illuminated a yellow, flashing MASTER CAUTION light on the glareshield in front of each pilot seat. Included in the caution/advisory panel were the following lights:

- a yellow CABIN DOOR light to indicate the cabin door was not secure;
- a green PASS OXYGEN ON light to indicate that pressure was present in the oxygen line to the passenger oxygen mask units;
- a green L BL AIR OFF light to indicate that the left bleed air valve was closed; and
- a green R BL AIR OFF light to indicate that the right bleed air valve was closed.

1.6.3.2 Aural warning systems

The aircraft was fitted with three devices that produced aural warning tones. They were:

- an altitude alerting device that sounded a chime and illuminated a light when the aircraft was 1,000 ft before the selected altitude. Another chime was sounded and light illuminated anytime the aircraft deviated 200 ft or more from the selected altitude;

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1 See ATSB Air Safety Occurrence Report 199902928 (particularly Attachment A) and Stanton, N. A., & Edworthy, J. (Eds.) (1999). Human factors in auditory warnings. Aldershot, UK: Ashgate.

2 An annunciator name written in upper case indicates the actual words or symbols shown on the annunciator.

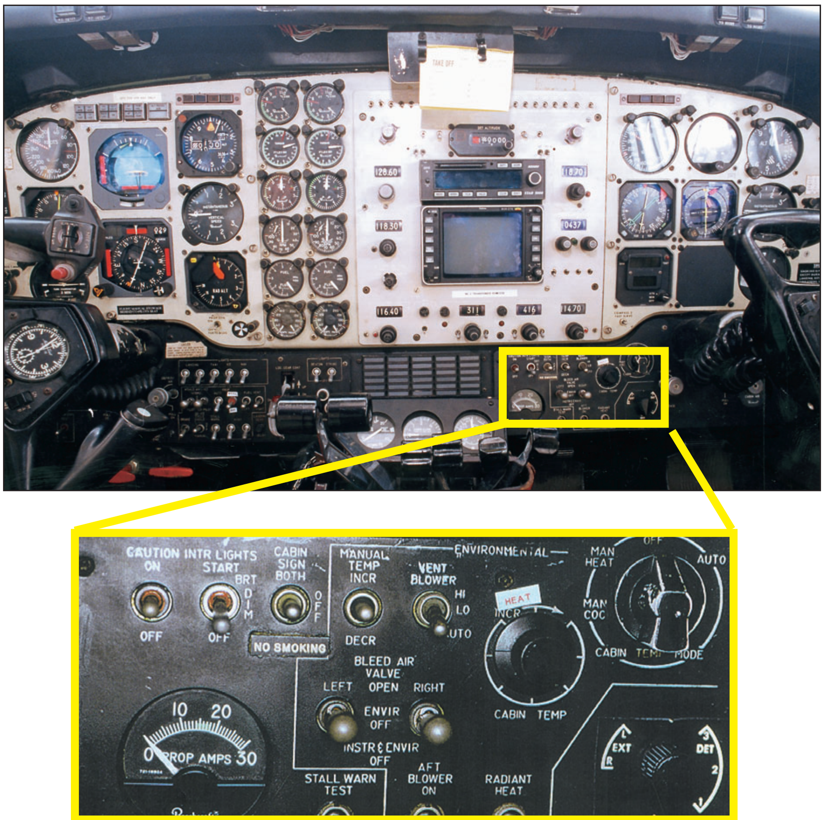
- a buzzer that sounded continuously whenever the aircraft's angle of attack exceeded a preset value indicating that an aerodynamic stall was imminent; and
- a horn that sounded intermittently whenever the landing gear was not locked down, in combination with various power lever and flap positions.

The aircraft was not fitted with a high cabin altitude aural warning device, nor was it required to be.

1.6.4 Pressurisation system

The cabin was pressurised with air taken from the compressor bleed air outlets of both engines. The bleed air supply was controlled using two three-position switches mounted side-by-side on the co-pilot's environmental sub-panel (figure 3). The bleed air switches were of a different shape from most other toggle switches on the instrument panel. The switches were detented so that they required lifting over a detent before changing position. The switches were placarded BLEED AIR VALVE (LEFT and RIGHT) and the individual switch positions were labelled OPEN, ENVIR OFF and INST&ENVIR OFF. When switched to either ENVIR OFF or INST&ENVIR OFF[3], the corresponding bleed air valve was closed. When the switch was in the OPEN position, environmental bleed air flowed into a heat exchanger, (or bypassed depending on the temperature selection), and then into the cabin for pressurisation and heating purposes. The aircraft manufacturer reported that with one bleed air system inoperative, maximum cabin differential would be maintained to 31,000 ft.

Figure 3:
Typical layout of a Beech Super King Air environmental sub-panel



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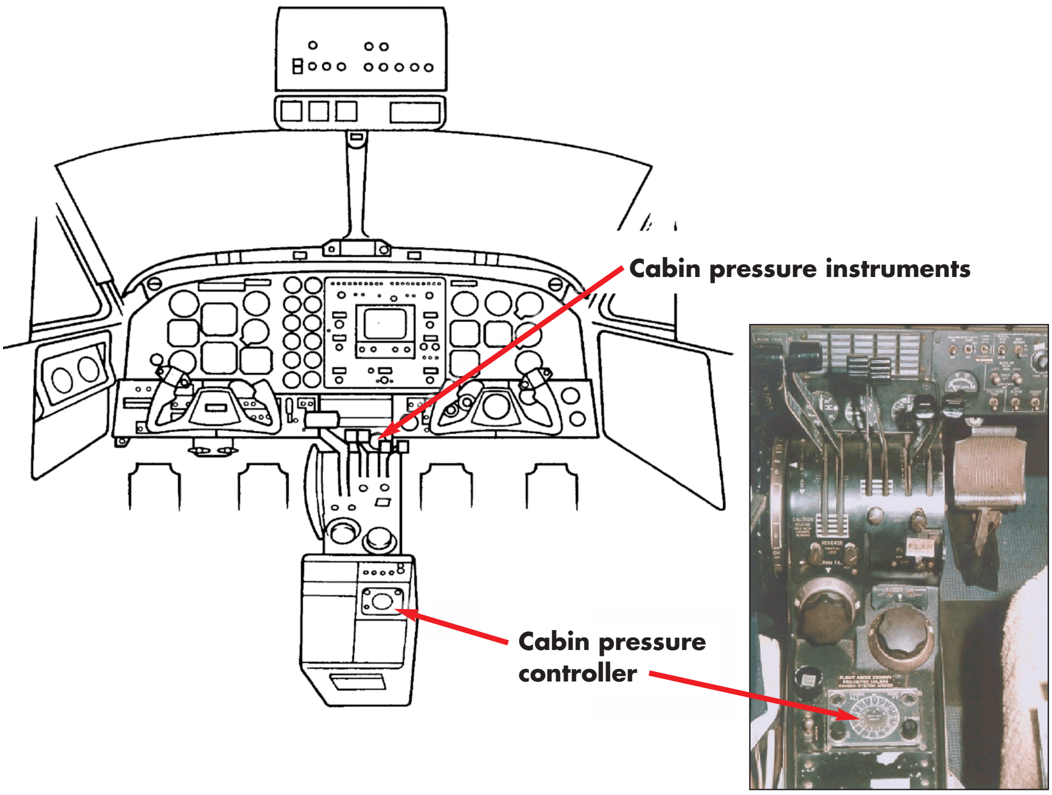
3 When the switch is in the ENVIR OFF position, the environmental flow control unit is closed and the pneumatic instrument air valve is open, providing air pressure for pneumatically operated instruments. In the INSTR & ENVIR OFF position, both the flow control unit and the pneumatic instrument air valve are closed.

An outflow valve located on the rear pressure bulkhead controlled the air flowing out of the cabin and was the primary means of maintaining cabin pressurisation. An adjacent safety valve prevented the pressurisation system from exceeding the pressure differential limit, in the event of a malfunction of the controller or the outflow valve.

The safety valve also allowed the cabin to be depressurised whenever the cabin pressure switch was moved to the DUMP position, and prevented the cabin being pressurised while the aircraft was on the ground (landing gear safety switch).

A cabin pressure controller was located on the centre pedestal between the pilot's seats. The location of the cabin pressure controller is shown in figure 4. It commanded the position of the outflow valve and allowed the pilot to select the desired level of cabin pressurisation. A dual-scale indicator dial was mounted in the centre of the cabin pressure controller. The outer scale indicated the cabin pressure altitude the controller was set to maintain. The inner scale indicated the maximum altitude at which the aircraft could fly without causing the cabin altitude to climb above the corresponding value on the outer scale. Both scales rotated together when the cabin altitude selector knob was turned. A rate control selector knob, also located on the cabin pressure controller, allowed the pilot to select the rate at which the cabin altitude changed.

Figure 4:
Location of Beech Super King Air 200 cabin pressure instruments and controls



A cabin pressure switch was also located on the centre pedestal. When the switch was in the DUMP position, the normally closed safety valve was pneumatically held open, preventing the cabin pressurising. When the switch was in the PRESS position, the pressurisation controller commanded the position of the outflow valve to allow the cabin to pressurise once the aircraft was in the air.

The cabin altimeter, located at the bottom centre of the instrument panel, continuously indicated the actual cabin pressure altitude on the outside scale, while the inside scale displayed the differential pressure between inside the cabin and outside. The cabin vertical speed indicator, located immediately to the left of the cabin altimeter, showed the rate of change of the cabin altitude. Both gauges were partly obscured from the pilot's view by the propeller levers when they were in the climb power position.

The bleed air introduced into the cabin for pressurisation was also the only form of cabin heating. If the air supply was interrupted, cabin heating was unavailable.

1.6.5 Oxygen system

The aircraft had an oxygen system to provide supplemental aviator's dry breathing oxygen to the aircraft occupants in the event of a loss of cabin pressurisation or the presence of smoke in the aircraft. It was not used during normal operations.

The oxygen bottle, located behind the aft pressure bulkhead, supplied oxygen to the two crew outlets in the cockpit, to the first aid oxygen outlet located at the rear of the cabin, and to the passenger oxygen system shut-off valve. A pressure regulator, located at the outlet end of the oxygen bottle, reduced the pressure of the oxygen flowing into the oxygen supply line.

A push/pull oxygen control handle, labelled PULL ON-SYS READY, was located in the cockpit roof lining. The handle operated a cable that opened and closed the oxygen shut-off valve. When the handle was pushed in, the valve was closed and no oxygen was available anywhere in the aircraft. When the handle was pulled out, the valve was opened allowing oxygen into the primary oxygen supply line (ie, the system was ready). The aircraft checklist required that the handle be pulled out prior to engine starting.

The aircraft had two oxygen pressure gauges, one in the co-pilot's lower right instrument panel for in-flight use, and one in the oxygen service panel for checking the oxygen pressure during the replenishment process. The gauges indicated the pressure in the oxygen bottle independent of the position of the shutoff valve.

1.6.5.1 Crew oxygen masks

A diluter-demand[4], quick-donning crew oxygen mask hung beside and aft of each of the two crew seats. The masks were normally connected to the aircraft oxygen supply. A lever on each mask had two positions of operation, NORMAL and 100 per cent. In the NORMAL position, the oxygen was diluted with air from the cockpit. In the 100 per cent position, pure oxygen was supplied. The AFM recommended that the selector levers were left in the 100 per cent position when the masks were not in use. An indicator in the line to each crew mask showed green when the line was pressurised and red/orange when line pressure was low or absent. Oxygen was available at each crew mask whenever the PULL ON-SYS READY handle was pulled out. Each mask was equipped with a microphone to enable the wearer to make radio transmissions when wearing the mask.

1.6.5.2 Passenger oxygen system

The passenger oxygen system was a constant flow system[5] that provided oxygen to the airline-type masks for use by passengers. The masks were contained within a number of dispensers in the ceiling of the cabin.

4 A diluter-demand mask supplied oxygen when the user inhaled and allowed the oxygen to be diluted with air drawn from the cabin.

5 A constant flow oxygen system gives a steady flow of oxygen to the mask, once it is activated by pulling down on the mask.

When the cabin pressure altitude exceeded approximately 12,500 ft, a barometric pressure switch automatically opened the passenger oxygen system shut-off valve. The pilot could also manually open the valve by pulling out the PASSENGER MANUAL ORIDE handle located beside the PULL ON-SYS READY handle in the cockpit roof lining. The two handles were identical in shape but coloured differently. During the investigation, King Air pilots reported to the ATSB that they sometimes pulled the PASSENGER MANUAL ORIDE handle instead of the PULL ON SYS READY handle during their Before Starting Engines Checklist actions. Provided there was sufficient residual pressure in the primary oxygen supply line, the passenger oxygen masks were released in the cabin.

Once the passenger oxygen system shut-off valve had been opened (either automatically or manually), oxygen should have flowed into the passenger oxygen supply line, triggering a green PASS OXY ON annunciator on the cautionary/advisory annunciator panel. The pressure in the passenger oxygen system supply line automatically opened the doors of the passenger oxygen mask dispensers, allowing the oxygen masks to drop. When each oxygen mask was pulled down by a passenger, a valve opened allowing oxygen to flow to that mask.

1.6.5.3 Contents of aircraft oxygen system

The oxygen bottle was removed from the aircraft in May 2000 and hydrostatically tested at a pressure vessel testing facility, where it was refilled. It was subsequently reinstalled in the aircraft.

The aircraft's documentation recorded that the oxygen contents were replenished a month before the accident. The investigation was unable to confirm whether the gas that was used to fill or replenish the aircraft's oxygen system met the specifications for aviators' dry breathing oxygen. There was no evidence that the contents of the oxygen system did not meet the required specifications.

Witness information indicated that on the day of the accident, the oxygen system pressure gauge was reading 1,500 lb/in^2. In the event of depressurisation, that quantity of oxygen should have been sufficient to provide oxygen to the pilot and passengers for 33 minutes. The calculation was based on the pilot and one passenger using crew masks and the remaining six passengers using passenger masks.

1.6.6 Autopilot/flight director system

The aircraft was fitted with a Collins FD108 flight director and a Collins AP105 autopilot system. The flight director could be used to display command information for the pilot when the aircraft was being flown manually. Alternatively, the flight director could be coupled to the autopilot, which would then control the aircraft in all three axes. Modes of operation of the flight director/autopilot (FD/AP) that were relevant to the occurrence are discussed here.

To control the aircraft in the horizontal plane, the FD/AP had the following modes:

- heading mode in which the FD/AP maintained the heading set by the heading bug on the pilot's horizontal situation indicator (HSI); and
- navigation/Localiser in which the FD/AP flew the course, relative to a navigation aid, that was selected on the pilot's HSI. If the selected navigation aid stopped transmitting or was out of range, the FD/AP would revert automatically to the heading mode.

Although the aircraft was fitted with a Global Positioning System (GPS) receiver, there was no GPS input to the FD/AP. Therefore, the aircraft was not capable of automatically maintaining a GPS track or flying to a GPS position.

To control the aircraft in the vertical plane, the flight FD/AP had the following modes:

- pitch-hold, in which the FD/AP maintained the pitch attitude selected by the pilot; and
- altitude-hold, in which the FD/AP maintained the altitude at which the altitude mode was selected.

The autopilot did not have an altitude-capture mode that would enable the aircraft to level off at a preselected altitude.

The autopilot was designed to disengage without pilot input following the loss of power to:

- the autopilot; or
- the vertical gyro; or
- any of the three autopilot servo motors which moved the flight controls.

It would also disengage if any of the three servo amplifiers began to operate outside of limits or the gyro was operating below speed.

A force applied to the flight controls, or the loss of power from one engine, would not result in the disengagement of the autopilot. The aircraft manufacturer advised that if an engine lost power while the autopilot was engaged, the aircraft would yaw towards the dead engine until the propeller was feathered. Once the propeller was feathered, the autopilot would be able to maintain heading and attitude, provided sufficient airspeed was maintained.

With the autopilot engaged in pitch-hold mode, an integrator circuit compared the actual pitch attitude of the aircraft to that selected by the pilot, and made elevator control commands to maintain the selected pitch attitude. In theory, the selected attitude could be maintained indefinitely. The autopilot manufacturer advised that in reality, each integrator had drift characteristics that would allow the pitch attitude to change over time. As the rate of drift was usually low, it would not be noticed on most flights where the pitch-hold mode was used in the climb and descent, and altitude hold mode was used for the cruise. However, where that mode was engaged over a long period, a significant change of pitch attitude could occur.

The manufacturer assessed that the profile flown by the accident aircraft was consistent with the operation of a serviceable autopilot engaged in the pitch-hold mode without any pilot input.

1.6.7 Fuel system

The aircraft had a main and an auxiliary fuel tank in each wing. The main fuel system for each engine consisted of six separate tanks; a nacelle tank, two wing leading edge tanks, two box section bladder tanks, and an integral (wet cell) tank. Each engine's leading edge tanks, box section tanks, and integral tank were interconnected to flow to the nacelle tank by gravity. The main and auxiliary fuel systems together fed fuel to the engine without pilot action required. Each engine, therefore, could continue operating until the fuel in its associated tanks was exhausted.

The aircraft departed Perth with 1,220 kg of fuel. Using the operator's fuel planning data, that amount of fuel gave the aircraft an endurance (to dry tanks) of 4 hours 25 minutes for a flight cruising at FL250. Because the aircraft flew above FL250, the fuel flow would have been lower and the endurance greater.

1.6.8 Radios

The aircraft was fitted with two very high frequency radios for communication with air traffic services.

A radio transmit button was located on the forward face of each of the two flight control wheels in the cockpit. A button was on the left side of the pilot's control wheel and on the right of the copilot's control wheel. Each radio transmit button was hidden from view by the associated control wheel.

The pilot normally used a headset with a boom microphone for making radio transmissions. A switch located on the lower instrument panel in front of each pilot allowed that pilot to select either the headset microphone or the oxygen mask microphone. The switch was normally left in the headset microphone position and was moved to the other position only after the pilot had donned an oxygen mask.

1.6.9 Pressure hull

All required maintenance and inspections of the pressure hull of the aircraft had been completed. Maintenance records showed that the last inspection of the rear pressure bulkhead was conducted in March 2000 and no defects were recorded.

Passengers who had flown in the aircraft during the 5 days before the accident reported hearing a hissing noise from the cabin entry door during takeoff, but the noise ceased immediately after the aircraft became airborne. The noise most probably was the result of the cabin door seal inflating when the aircraft left the ground and therefore was normal.

1.6.10 Weight and balance

The load for the flight included the eight occupants and their personal baggage. The baggage was loaded into the baggage area at the rear of the aircraft cabin. The aircraft was calculated to have departed Perth at a weight of 5,442 kg, which was less than the maximum take-off weight of 5,700 kg. Assuming the occupants remained seated, the centre of gravity was calculated to have remained within the allowable range for the flight.

As the fuel in the auxiliary fuel tanks was used, the centre of gravity moved forward, then as the fuel in the main tanks was used, the centre of gravity moved towards the rear of the aircraft.

There was no evidence to suggest that any dangerous goods were carried on the aircraft during the flight.

1.6.11 Serviceability

The maintenance release was current and an examination of the aircraft's maintenance records found no recurring maintenance problems that may have been factors in the accident.

A pilot who flew the aircraft on the morning of the occurrence reported that the aircraft was fully serviceable. In particular, the pressurisation system operated normally during the flight at FL250, maintaining a pressure differential of 5.4 lb/in^2 and a cabin altitude of 7,500 ft.

The manufacturer's maintenance manual did not include a requirement to perform any ongoing functional tests of the barometric switches that activated the cabin altitude alert and automatic passenger oxygen systems. There was no evidence that the switches had been changed or tested since 1990. The serviceability of the barometric switches in the aircraft, therefore, could not be determined.

1.6.12 Operating procedures and checklists

The aircraft operator's procedures and checklists that were available to the pilot were not considered factors in the accident.

1.6.13 Climb performance

The service ceiling of the aircraft was calculated to be about FL340, which corresponded with the height at which the aircraft stopped climbing.

1.7 Meteorological information

When the aircraft departed Perth, visual meteorological conditions existed with patches of cloud between 3,000 and 4,000 ft. Meteorological reports indicated that the remainder of the flight was in clear conditions. The crews of chase aircraft reported that they had no difficulty observing the accident aircraft from several miles away.

No airframe icing was forecast at the levels flown by the aircraft and none of the intercept aircraft were subjected to airframe icing. At FL250 (25,000 ft), which was the planned cruising altitude of the flight, the forecast outside air temperature was approximately -24°C. The forecast temperature at FL340 (34,000 ft) was approximately -42°C.

Meteorological conditions were not considered factors in the accident.

1.8 Air Traffic Services

One ATS controller assumed responsibility for the aircraft from the time it climbed through FL130 until the time it flew outside radar coverage. The controller advised that the radio transmissions and movements of the accident aircraft appeared normal until 1032. The controller then observed that the aircraft had climbed through its assigned altitude of FL250. When he queried the pilot about the altitude and received the reply, "Sierra Kilo Charlie–um–standby", the controller reported that he thought the pilot was pre-occupied with a problem with the aircraft and would advise his intentions when he had time. He provided the pilot with a 'block altitude' clearance to permit the aircraft to fly at levels above FL250 in anticipation of a request by the pilot to return to Perth.

When he heard the open microphone transmissions, the controller thought that the pilot had a further problem involving the aircraft's radios. When the open microphone transmissions ceased and the pilot did not respond to communication checks, the controller then suspected that the pilot might be incapacitated or hypoxic. The controller then advised his supervisor of the problem and together they completed the In Flight Emergency Response (IFER) Checklist. The IFER Checklist at the time of the accident did not include procedures for incapacitation/hypoxia. Subsequent to the accident, Air Services Australia amended the In Flight Emergency Response Checklist to incorporate procedures to be followed by air traffic controllers, when a controller suspects that a pilot has been affected by hypoxia.

1.9 Communications

A transcript of all radio communications between ATS and the pilot is contained in Attachment B.

Radio communications between the pilot and ATS controllers were recorded. Communications systems operated normally and were not considered factors in the occurrence. The AVR recorded everything that the assigned controller heard, including all transmissions on all the frequencies that the controller was monitoring, all ground communications with other ATS personnel and various alert tones that were generated by the controller's console.

The AVR recording system contained many components, including satellite communication links, which affect the quality and bandwidth of the recorded signal. On the day of the occurrence, the AVR system recording the transmissions from the aircraft recorded only the sounds that were in the frequency band of 250 to 2,350 hertz. Thus, some of the higher frequencies of the pilot's voice and some sounds from within the aircraft were not recorded. Accordingly, the analysis that was conducted, and the conclusions that could be drawn from the AVR information were limited. An AVR bandwidth of 50 to 4,000 Hz was necessary for thorough analysis of speech, while a bandwidth of 50 to 3,500 Hz would enable a comprehensive analysis of the background noise within an aircraft.

1.10 Aerodrome information

Not a factor in this occurrence.

1.11 Flight recorders

The aircraft was not equipped with a flight data recorder or cockpit voice recorder, nor was it required to be.

1.12 Wreckage and impact information

1.12.1 Accident site description

The accident site was gently sloping land covered with dry, long grass and scattered small trees and was approximately 62 m (200 ft) above mean sea level.

The aircraft collided with the ground on a heading of about 320°M, in a shallow descent and in a left wing low attitude. See the wreckage plot, Attachment A for a diagram of the location of major items of wreckage.

The fuselage had ruptured at impact, scattering items from the aircraft's interior along the length of the wreckage trail.

1.12.2 Structures

The structure of the aircraft disintegrated during the collision sequence. The cockpit, centre fuselage, tail cone and fin were held together by various cables. The wings had broken into many pieces. Evidence from the examination of the landing gear was consistent with it being in the retracted position at impact.

1.12.3 Flight controls

All extremities of the wings, flaps, tailplane and vertical fin were accounted for. All flight controls appeared to have been present on the aircraft at the time of the aircraft's impact with the ground. As far as could be ascertained, all control cable connections were securely attached at the time of the impact. The positions of the flaps, flap selector handle, aileron, rudder and elevator trim tabs could not be determined, due to the break up of the aircraft. No evidence was found during the investigation to indicate other than normal operation of the flight controls at the time of the accident.

1.12.4 Engines and propellers

In each engine, there was evidence of rotational damage on both the compressor and power turbine assemblies, indicating that both sections of the free-turbine engine were turning at impact. There was evidence of a pre-existing leak of bleed air through the gaskets at the P3 customer air outlet on each engine. The leaks were considered minor and were not factors in the occurrence.

There was evidence of rotational damage to both propeller assemblies. The blades of the left propeller made four distinct slash marks in the ground, and the blades of the right propeller made three. No evidence was found that indicated other than normal operation of the propellers at the time of the accident.

The distances between successive propeller slash marks indicated a groundspeed at impact of 239 kts.

Ground scars and the damage to the engines and propellers indicated that both engines were operating and developing power at the time of ground impact.

1.12.5 Fuel tanks

The fuel tanks in both wings were damaged by fire. The tanks in the left wing had some areas of sooting and a small amount of melting damage. The metal skin over the left auxiliary tank was blown outwards, suggesting an explosion within the tank at, or just after ground impact. The right wing tanks had extensive damage and melting because of fire.

1.12.6 Pressurisation system

There was nothing found during the examination of the aircraft's bleed air system components that indicated any pre-existing problem that would have affected their operation at the time of the accident. The altitude selector knob on the pressurisation controller was jammed by impact damage at a position equivalent to 26,000 ft. Although the rate controller setting knob was found in the maximum rate position, the control was free to rotate. It was not possible to determine whether the knob had been in the maximum rate position prior to the collision or was moved by impact forces.

Except for the cabin pressure controller panel, the instruments and controls for the pressurisation system were destroyed in the post-impact fire, rendering conclusions impossible. The outflow valve and safety valve were both severely damaged by fire, but there was nothing found to suggest that they were not serviceable before impact.

The air flow control valves that controlled the flow of engine bleed air to the cabin were examined by their manufacturer under the supervision of an US National Transportation Safety Board (NTSB) investigator. The butterfly shutoff valve in the left engine flow control valve was found in the closed position. However, as the valve was moved to that position by a spring, and the valve was undamaged, it could have moved to that position after the initial impact. The butterfly shutoff valve within the right engine flow control valve was found jammed in the 83-degree position, which corresponded to the fully open position of a serviceable valve.

1.12.7 Oxygen system

The oxygen bottle was empty and its regulating valve was loose. Fire and impact forces damaged both. A crew oxygen mask connection socket and mask connector were recovered in the fully coupled state indicating that the mask assembly was connected to the aircraft at the time of impact. All the passenger oxygen mask containers had separated from the roof of the cabin during the impact sequence or had been destroyed in the fire. The oxygen system pressure gauge from the cockpit was destroyed by fire.

No evidence was found to suggest that the oxygen system was unserviceable at the time of impact. Due to the extreme damage to the aircraft, it was not possible to determine:

- the quantity, if any, of oxygen in the system at the time of impact;
- the positions of the oxygen system controls prior to impact;
- whether the passenger oxygen masks deployed or had been used during the flight; or
- whether either of the two crew masks had been used during the flight.

1.12.8 Pressure hull

The remains of tinted internal trim windowpanes, external windows panes, cockpit windows, and both windscreens were found at the accident site. The damage was consistent with having occurred during the impact sequence.

It was not possible to determine whether any ruptures in the pressure hull were present before impact, because the fuselage broke up during the impact sequence and was damaged by the post-impact fire.

1.12.9 Cabin door

The cabin door was found approximately 25 m from the main wreckage. It was intact except for one broken locking hook and pieces of the rubber door seal, all of which were found in the early part of the wreckage trail. The damage sustained was consistent with the door separating from the fuselage as the aircraft struck the ground in a left wing-low attitude.

The examination of the cabin door revealed that it appeared to have been in the closed position and correctly locked at the time of the ground impact, and that there was no evidence of any pre-existing damage to the door or its seal.

1.12.10 Cockpit instruments and controls

The numeric display on the altitude alert device was indicating midway between 25,000 and 25,100 feet. Impact forces probably moved the 100 ft digit wheel from the even thousand feet position.

The engine controls, flight controls and associated control cables had been severely disrupted during the impact sequence and fire. It was not possible to determine the pre-impact position or serviceability of the controls.

1.12.11 Warning/caution lights

The warning annunciator panel was found separate from the burnt cockpit area and was relatively undamaged. The panel incorporated the engine bleed air fail and cabin altitude warning captions among the warning lights. Examination of the light bulbs within the panel revealed that all filaments were intact, indicating that none of the light bulbs were illuminated at the time of impact. The cabin altitude warning caption would not have been illuminated at the time of the collision with the ground because the ground elevation of the site was near sea level.

The caution/advisory annunciator panel, the master warning lights, and master caution lights were all destroyed by fire.

1.13 Medical and pathological

Post-mortem examinations of the aircraft occupants were conducted in Brisbane 3 days after the accident, and included toxicological testing of tissue samples. The high ambient temperatures at the accident site, and the time between the accident and the post-mortem examination, resulted in some decomposition of the tissues before the examinations were conducted.

1.13.1 Autopsy results

The post-mortem examinations determined that all occupants of the aircraft had sustained multiple injuries during impact that would have proved fatal. The examination, however, could not determine the exact causes of death of the occupants.

The results of the post-mortem examination did not indicate any pre-existing medical condition, which may have rendered the pilot incapable of operating the aircraft.

The results of the examination to determine if the occupants had undergone freezing due to prolonged exposure in an unheated environment were inconclusive.

There were no indications that the occupants of the aircraft had inhaled products of combustion or any other irritant material.

1.13.2 Toxicology

Carbon monoxide is a gas found in engine exhaust gases and is a common gaseous product of a fire in confined spaces, such as inside a building. It produces symptoms that are similar to hypoxia and is fatal in sufficient concentrations. Testing revealed that carbon monoxide was not a factor in the occurrence.

Cyanide gas (hydrogen cyanide) is a toxic gas produced by the burning of materials commonly found in aircraft interiors. Cyanide can also be produced in the tissues during the decomposition process, consequently a high level found during testing would not reliably indicate that the subject was exposed to cyanide. However, a test result showing a low level of cyanide in the tissue was considered a reliable indicator that the subject was not exposed to cyanide. Testing revealed that there was a low level of cyanide in the tissue and therefore, cyanide gas was not a factor in the occurrence.

The investigation identified that the following toxic substances formed part of the aircraft systems:

- Jet A-1 fuel;
- engine oil;
- hydraulic fluid in the brake system and the cabin door hydraulic dampener;
- airconditioning compressor oil;
- Freon R12 (dichlorodifluoromethane) refrigerant in the airconditioning system;
- BCF (bromochlorodifluoromethane) in two cabin fire extinguishers; and
- fuel additives (Mil-I-85470A and Biobor JF).

Tissue samples were tested for volatile organic compounds (VOCs), Freon R12 and BCF. The results of the tests were negative.

1.13.3 Hypoxia

Hypoxia is the state of oxygen deficiency in the tissues and can be the result of many factors, including some respiratory and cardiovascular conditions, pharmaceutical drugs, toxic substances, poor blood circulation, or breathing a low partial pressure of oxygen (low air pressure). Brain cells have a uniquely high oxygen demand and are most susceptible to low oxygen levels. Brain impairment, deterioration of performance, reduced visual function, unconsciousness, and death can occur as a result of hypoxia.

Vision is particularly sensitive to hypoxia. Moderate and severe hypoxia causes a restriction of the visual field, with loss of peripheral vision. There may also be a subjective darkening of the visual field. Auditory acuity (hearing sensitivity) is also reduced by moderate and severe hypoxia, but some hearing is usually retained even after other senses such as vision are lost.

Hypobaric hypoxia, also called hypoxic hypoxia or altitude hypoxia, is a result of a deficiency in alveolar oxygen exchange that may be due to a reduction in the oxygen partial pressure (tension) in inspired air or a reduction in the effective gas exchange area of the lung. The result is an inadequate oxygen supply to the arterial blood, which in turn decreases the amount of oxygen available to the tissues. In aviation, breathing air at low barometric pressure frequently causes hypobaric hypoxia. It can be prevented by pressurising the aircraft cabin (typically to pressure altitudes of 10,000 ft or below) or by the aircraft occupants breathing supplemental oxygen. In the aviation context, hypobaric hypoxia rarely leaves any signs that would be detectable at a post mortem examination.

The clinical features of acute[6] hypobaric hypoxia include the following:

- impairment of cognitive skills such as judgment, decision-making, memory, self-regulating, and self-awareness;
- impaired psychomotor coordination and reaction times;
- restriction of visual field, reduced colour discrimination, reduced auditory acuity and cyanosis (skin turning blue); and
- loss of consciousness, finally resulting in death.

6 Acute can be described as the "rapid onset" of symptoms as would occur during a rapid or sudden depressurisation, or when climbing at a rate in excess of 500 ft/min unpressurised, above 15,000 ft in the aviation environment. Chronic or slow onset hypoxia may occur to mountain climbers as they ascend over a period of days or weeks.

Some of the subjective symptoms of hypobaric hypoxia include euphoria, light-headedness, dizziness and feelings of warmth. An insidious aspect of hypobaric hypoxia is that it can create a false sense of well being at the same time as it is degrading the subject's mental and physical performance. In most cases, the initial signs are subtle and the pilot has limited time to recognise the signs, make decisions, and carry out the actions to rectify the situation. Depending on the degree of exposure to the hypobaric environment, higher mental functions such as thinking and concentration can be impaired before any degradation of physical abilities becomes apparent. For example, a hypoxic pilot may be quite capable of pressing the transmit button but may be unable to form the words to speak.

The symptoms of hypoxia are covered in detail in Attachment D.

1.13.4 Time of useful consciousness

The amount of time available to an individual breathing air at a given pressure altitude before the ability to perform directed tasks is lost, is often referred to as time of useful consciousness (TUC), or effective performance time (EPT). It can vary from a few seconds to many minutes, depending on the cabin pressure altitude and how rapidly it increases. The AFM stated that the TUC was approximately 3 to 5 minutes at 25,000 ft for an average individual, and at 30,000 ft it was approximately 1 to 2 minutes. TUC data is expressed as a range of times within which 68 per cent of TUCs for individuals exposed to those conditions would lie.

All published TUC information is based on a rapid decompression in an aircraft at a constant altitude. If the decompression is more gradual, TUC times are longer. No TUC data could be located for occupants of a climbing aircraft that failed to pressurise, or that experienced depressurisation.

The studies upon which these times are based were conducted using comfortably seated participants who were expecting a depressurisation and who were asked to perform simple repetitive tasks (such as counting backwards from 1000) until they could no longer accomplish them.

The US NTSB, after investigating a loss-of-pressurisation accident to a Learjet 35 aircraft, concluded;

> that existing guidance and information on TUC is inconsistent and misleading because it does not accurately reflect TUC for pilots trying to perform complex tasks in an emergency environment. It fails to convey to flight crews the urgency of donning oxygen masks immediately after a loss of pressurisation at relatively high altitudes. Therefore, the Safety Board believes that the [Federal Aviation Administration] FAA should revise existing guidance and information about high-altitude operations to accurately reflect the TUC and rate of performance degradation following depressurisation and to highlight the effect of hypoxia on an individual's ability to perform complex tasks in a changing environment.[7]

An illustration of the variability of TUC times between individuals was the different reactions to the high cabin altitude of the pilot and the passengers in occurrence ATSB 199902928. In that occurrence, the pilot collapsed shortly after the aircraft reached 25,000 ft unpressurised. One passenger, although subjected to the same cabin altitudes as the pilot, remained conscious, took over control of the aircraft and descended it to

7 NTSB Safety Recommendation A—00-109 through -119

below 10,000 ft. The other passenger also remained conscious and placed the oxygen mask on the unconscious pilot. Neither passenger used supplemental oxygen, although the passenger took several breaths of oxygen from the pilot's mask before placing it on the pilot.

In summary, incapacitation may occur in less than the published TUC values, and therefore, the values provide guidance only.

1.14 Fire

Eyewitnesses to the impact reported that they could see no signs of fire until the aircraft collided with the ground. Immediately after, a fireball was visible. A small ground fire persisted for several hours after the impact. There was no evidence of any pre-impact fire.

1.15 Survival

The occurrence was not survivable.

1.15.1 Search and rescue

After being advised by ATS staff of the details of the emergency, AusSAR requested two aircraft to be diverted to intercept the accident aircraft. Another two aircraft were tasked to intercept the aircraft in the Alice Springs area. Assistance from the Australian Defence Force was requested, but no military aircraft could reach the King Air's predicted track before the time of predicted fuel exhaustion. Other civilian aircraft at Mt Isa were prepared to intercept the aircraft but were not required. A Queensland Emergency Services helicopter flew to Normanton to respond to the occurrence as soon as the location of the impact was known and went to the accident site at first light.

AusSAR provided the location of the accident site to the Burketown police who sent a ground party to the accident site. The owner of the property on which the accident occurred, provided staff to assist the police to locate the site. When the ground party arrived at the site approximately 2 hours after the collision, they found no survivors.

1.15.2 Crew and passenger seats and seatbelts

The aircraft had two pilot seats at the front and ten passenger seats in the cabin. All seats, except for the right pilot seat, were found at various distances from the wreckage of the fuselage. The remains of the right pilot seat were found within the wreckage of the cockpit, but due to extensive fire damage, it could not be determined if the seat remained attached to the fuselage.

The two pilot seats were each fitted with a four-point, inertia reel seatbelt. The right pilot seat and belt had been burned in the fire but the buckle, including the shoulder strap attachments, was found in the cockpit in a fastened state. The left pilot seat had been thrown clear of the main wreckage fire and was not burned. It was damaged but largely intact. When found, the seat belt was not fastened.

Each passenger seat was fitted with a two-point seatbelt. As all the passenger seats separated from the fuselage during the break-up sequence, it was impossible to relate each seat and belt with a location in the aircraft. The buckles of five belts were found unfastened and undamaged. One buckle was found fastened. Another had damage, which was consistent with it being fastened at impact. Another buckle was found with minor damage that suggested that the buckle was not fastened at impact. The remaining two seatbelt buckles were not found.

1.15.3 Emergency locater transmitter

An emergency locater transmitter (ELT) was installed in the rear of the fuselage, aft of the rear pressure bulkhead. It was destroyed during the collision and post-impact fire.

1.16 Organisational and management information

Not a factor in this occurrence.

1.17 Related occurrences

A number of prior occurrences involving similar factors include:

BASI Occurrence 199003527
In November 1990, a Beech Super King Air 200 was flying at FL310 (31,000 ft) with a cabin altitude of 18,000 ft and with the pilot breathing through his oxygen mask. Ten minutes after reaching cruise altitude, the pilot felt tingling in his fingers. After checking his mask and oxygen system, the pilot decided to descend to FL120 (12,000 ft). As the aircraft left FL310 he removed his oxygen mask. Three to four minutes later, the pilot's symptoms were rapidly getting worse, so he put his mask on again. Later describing his symptoms, the pilot said,

> I was barely able to move my arms, legs and hands. My hands were locked solid in a fist. My face felt distorted and speech was severely impeded. I was having considerable difficulty breathing with the mask on or off. Once level at FL120 (12,000 ft) (cabin altitude 8,000 ft) it took approximately 90 minutes to return to normal.

The investigation found that the pilot had not used the oxygen system correctly.

NTSB occurrence IAD97FA060
In April 1997, the pilot of an unpressurised Cessna 337 was cleared to climb to FL250 (25,000 ft) for the purpose of taking some high altitude photographs near Hickory, Pennsylvania, USA. When the controller queried the pilot about exceeding his assigned altitude, the pilot did not respond. The aircraft was observed to climb to FL270 (27,700 ft) before it entered a rapid, uncontrolled descent and broke up. Investigation found that the aircraft's portable oxygen bottle had been filled with compressed air instead of oxygen. That resulted in the crew being incapacitated by hypoxia.

ATSB occurrence 199902928
In June 1999, as the Beech Super King Air 200 aircraft levelled at FL250 (25,000 ft) under autopilot control, a passenger seated in the co-pilot's seat noticed that the pilot was acting erratically. Soon after, the pilot slumped forward over the controls and became unconscious. The passenger, who was also a pilot but not endorsed on the aircraft type, assumed control of the aircraft. After disconnecting the autopilot and commencing a descent, he asked the other passenger to fit an oxygen mask to the unconscious pilot. An emergency was then declared to air traffic control, stating the situation and that the aircraft was on descent to 5,000 ft. The descent was stopped at 6,000 ft to prevent the aircraft entering cloud. During the descent the pilot regained consciousness. When the passenger was satisfied that the pilot had regained full

situational awareness, control of the aircraft was handed to him. The pilot then returned the aircraft to the departure aerodrome.

The investigation found that the pilot had inadvertently selected the bleed air valve switches to the ENVIR OFF position as the aircraft climbed through 10,000 ft. That disabled the aircraft's pressurisation system. A passenger later reported seeing the red ALT WARN annunciator light on, but not the flashing master warning light. The passenger oxygen masks did not deploy at FL125 (12,500 ft) because the panels on the mask dispenser units had been incorrectly installed. Twenty minutes elapsed between the time the aircraft passed FL150 (15,000 ft) in unpressurised climb and the time the pilot collapsed.

ATSB occurrence 200105188
The Beech Super King Air 200 was on an air ambulance flight from Timber Creek, Northern Territory, to Tindal with the pilot in command, a flight nurse and one injured passenger on board.

After take-off, the pilot was cleared to fly to Tindal by a non-direct route and became pre-occupied with programming the aircraft's Global Positioning System (GPS) navigation unit. As the aircraft climbed through FL125 (12,500 ft), the flight nurse noticed that the passenger oxygen masks had deployed and advised the pilot. After momentarily looking at the masks in the cabin, the pilot looked back to the instrument panel and noticed that the red ALT WARN annunciator was lit and that the MASTER WARNING lights were flashing. The pilot then descended immediately to 10,000 ft where he found that both bleed air switches were in the ENVIR OFF position. In that position, no bleed air was available for aircraft pressurisation.

Australian Defence Force flying Safety Spotlight magazine, edition 3/2001
The front seat pilot of a military Pilatus PC9 on a transit flight at FL200 (20,000 ft), felt unwell and handed over the flying of the aircraft to the backseat pilot. Before the flight, the front seat pilot had reported feeling the early signs of a cold. Both pilots felt that the front seater's inflight symptoms were the result of the worsening cold and agreed to continue the flight. When the front seat pilot's speech and thought processes deteriorated even further, the back seater became concerned about hypoxia and instructed the front seater to replace his oxygen mask and select 100 per cent oxygen. The front seater now advised that he felt marginally better, but did not resume flying. Due to being on minimum fuel and having no suitable diversion airfields, they did not descend the aircraft until the descent point for their destination. After landing, it was discovered that the front seat pilot's oxygen mask line was not connected to the aircraft oxygen outlet, resulting in him becoming severely hypoxic. During the flight, he had experienced feelings of confusion and claustrophobia, and at one stage, had considered ejecting, although he had not mentioned that to the other pilot.

1.18 Tests and research

1.18.1 Analysis of background cabin noise

The analysis of background noise revealed that the propellers were turning at 1900 RPM, which was the rotational speed expected to be set for the aircraft climb.

The analysis also revealed that at 1032:50, a discrete frequency component at 1,350 Hertz increased in amplitude and then increased in frequency. The analysis concluded that the frequency component could have been caused by one of three possible scenarios:

- the aircraft pressure differential at 1032:50 was small and no frequency component was present. The aircraft pressure differential may have subsequently slowly increased causing the frequency component; or
- air flowing through an opening in the aircraft. As the aircraft pressure differential increased, the amount of air flowing through the opening may change, changing the frequency and amplitude of the frequency component; or
- the frequency component was a result of a signal induced by a device or component that was not present on the previous VH-SKC flights or other King Air aircraft used in comparison testing.

Because the analysis of the frequency component was inconclusive, the investigation could not draw a conclusion regarding its significance to the occurrence.

1.18.2 Analysis of pilot's speech and related behaviour

During the investigation, the ATSB requested two independent analyses of the pilot's speech and related behaviour during the accident flight. A team from the NTSB conducted one, and a team of two forensic phoneticians based in Australia conducted the other.

The two analyses provided similar results and conclusions. Detailed results are presented in Attachment C. The investigation's analysis of the radio transmissions from the aircraft concluded that the pilot's speech at 1032:59 was significantly different from his speech during the previous transmissions. He was slower to respond to the controller, keyed the microphone a relatively long time before speaking, spoke more slowly, and did not answer the controller's question or make an appropriate response. The pilot's speech also showed evidence of imprecise pronunciation.

The open microphone transmissions from the aircraft included the sound of breathing. The NTSB team noted that there was a pattern of alternation between apnoea (no breathing) and hyperventilation (breathing at an abnormally high rate) during the 8 minute period of the open microphone transmissions. The NTSB report stated:

> Such periodic breathing irregularities (known as "Cheyne-Stokes" irregularities) are typically observed during comatose states resulting from mild brain damage, such as following a stroke. However, periodic breathing has also been observed to result from hypoxia (Ghazanshahi, 1993), both in the sleeping patterns of climbers and healthy subjects at high altitude (Mizuno, 1993; Salvaggio, 1998) and among conscious subjects experiencing high altitude in test chambers (Salvaggio, 1998; Waggoner, 1984; Lhoo, 1982) and airplanes (Busch, 2000). Since the pilot may have been conscious during part of the time that he displayed periodic breathing, hypoxia offers one of the few explanations documented in available medical literature that may account for the observed breathing irregularities.

The investigation's analysis of the radio transmissions concluded that the pilot was probably not wearing an oxygen mask during the transmissions because audio signatures associated with the wearing of an oxygen mask were not present. The NTSB analysis also concluded that the pilot experienced rapid impairment that probably led to a loss of consciousness in about 4 minutes.

1.18.3 Tests of oxygen system indications

As covered in section 1.6.5.2, Beech Super King Air 200 pilots reported that they had, on occasions, pulled the PASSENGER MANUAL OverRIDE handle instead of the PULL ON SYStem READY handle during their Before Starting Engines Checklist actions. To assess whether pulling the wrong handle could result in a situation where the pilot believed that the oxygen system was ready, when in fact it was not, a number of tests were completed using a Beech Super King Air 200, similar to the occurrence aircraft. The tests were carried out as though the pilot was performing the oxygen system checks for the first flight of the day. The tests indicated that:

- if there was sufficient oxygen pressure (from the previous flight) in the primary oxygen line to give a green indication on the oxygen pressure indicator in the line to each crew oxygen mask, pulling the PASSENGER MANUAL OverRIDE handle would release the passenger oxygen masks. That would give a positive indication to the pilot that the incorrect handle had been operated; and
- if there was insufficient oxygen pressure in the primary oxygen line to cause the passenger masks to be released when the PASSENGER MANUAL OverRIDE handle was inadvertently pulled, then the oxygen pressure indicator would show red. There would be insufficient pressure available for the pilot to get one complete breath through a crew oxygen mask. Accordingly, there would be two positive indications to the pilot that the incorrect handle had been operated.

The tests indicated that the design of the Beech Super King Air 200 oxygen system made it unlikely that a pilot could pull the wrong oxygen handle and not be aware of the error providing the appropriate checks were performed.

2 ANALYSIS

2.1 Aircraft operation

The investigation concluded that the aircraft was probably serviceable before it departed Perth. The operation of the aircraft during the departure and up to FL156 and until 1032 appeared to be normal. The altitude that the aircraft ultimately climbed to, and the analysis of the background cabin noise indicated that climb power was set before the pilot became incapacitated. The steady heading flown by the aircraft from position DEBRA until just before it impacted the ground suggested that the autopilot was engaged before DEBRA and remained engaged for the remainder of the flight. The vertical profile flown by the aircraft was consistent with the autopilot being engaged in the pitch hold mode. The design of the aircraft systems were such that, with the autopilot engaged, the engines would continue to operate and the aircraft would continue to fly without human input until it was disrupted by other events, such as collision or fuel exhaustion.

The absence of extensive fire damage in the wreckage of the left wing suggested that at the end of the flight, the left main and auxiliary tanks were almost empty. The near-exhaustion of fuel in the left wing tanks may have produced at least one, and probably several, momentary losses of left engine power shortly before all power was lost. As the autofeather system was normally switched off after takeoff, the left engine would not have feathered during one of these momentary power losses. At the relatively high speed the aircraft was flying during the descent, the drag of an unfeathered propeller probably exceeded the authority of the autopilot and the aircraft yawed and rolled towards the left engine, as was observed shortly before the aircraft collided with the ground.

2.2 Incapacitation

The results of the post-mortem examination did not indicate any pre-existing medical condition which may have rendered the pilot incapable of operating the aircraft. The analysis of the pilot’s voice and breathing during the radio transmissions made after the aircraft had climbed through FL256, suggested that he was significantly impaired and that towards the end of the period of transmissions, he was probably close to being, or was unconscious. The absence of sounds indicating attempts by the passengers to revive the pilot suggested that they might also have been incapacitated. The possibility of the pilot alone being incapacitated by a medical condition such as a stroke or heart attack would appear unlikely, given that there was no apparent activity or action by the other occupants of the aircraft for the duration of the flight.

The results of the post-mortem examinations and the toxicological testing, and the absence of coughing during the transmissions from the aircraft, indicated it was unlikely that any toxic substances incapacitated the occupants. The low carbon monoxide and cyanide levels, the absence of irritation in the airways of the occupants, and the examination of the wreckage indicated that a fire in the cabin was unlikely to have occurred.

2.3 Hypobaric hypoxia

The lack of evidence supporting the presence of toxic fumes and the speech and breathing symptoms displayed by the pilot during the radio transmissions associated with the observed lack of movement within the aircraft, indicated that the occupants were probably incapacitated by hypoxia. The occupants were probably incapacitated by hypobaric hypoxia as a result of inadequate cabin pressurisation.

2.4 Pressurisation system

The inconclusive nature of the findings relating to tissue freezing resulted in the investigation being unable to assess whether the cabin heating was operating throughout the flight.

If one bleed air valve had malfunctioned and prevented normal supply of bleed air, or the pilot inadvertently selected it to the ENVIR OFF or INST&ENVIR OFF position, the airflow through the functioning valve should have been sufficient to maintain maximum cabin pressure to FL 310. Consequently, the malfunction or inadvertent closure of one bleed air valve, in isolation, should not have resulted in the impairment of the aircraft occupants.

The lack of pressurisation was due to insufficient air flowing into the cabin and/or as a result of air flowing from the cabin that exceeded the capacity of the pressurisation system. These conditions could have been a result of someone making an inappropriate switch selection (such as the occurrence reported in ATSB report 199902928) or due to a mechanical failure. Due to the lack of evidence, the investigation could not determine whether the depressurisation was a result of human error or mechanical failure. The audio analysis that revealed the discrete frequency component at 1,350 Hertz at 1032:50 could not determine whether the sound was associated with any event that may have been a precursor to the accident.

During an explosive or rapid depressurisation of a pressurised aircraft, however, the noise, pressure changes, temperature changes and draughts within the cabin would have alerted the occupants that a substantial failure had occurred. The considerable noise resulting from a rapid or explosive depressurisation would have likely produced a noise signature detectable in AVR recordings. In the absence of such a noise signature, the investigation concluded that a rapid or explosive depressurisation probably did not occur.

The absence of a distress radio call, or an attempt to descend the aircraft, and the likelihood that the pilot did not don his oxygen mask, suggested that the pilot was unaware that the aircraft was unpressurised or depressurising. The occupants may not have noticed a subtle and gradual depressurisation or the aircraft climbing unpressurised, until an on-board system provided an indication of the problem, for example, a warning light or the deployment of the passenger oxygen masks. Crew oxygen masks do not deploy and require crew action to don them. If the passengers were asleep, they may have not have noticed deployment of the passenger oxygen masks or the illumination of a warning light. Had the passenger masks automatically deployed, it is questionable whether the pilot would have noticed the deployment. Due to the substantial break up of the wreckage, (and the fact that a visual warning would not have continued as the altitude decreased prior to impact) the investigation could not determine whether the warning systems and masks operated correctly.

2.5 Oxygen system

Due to the extensive impact and fire damage to the wreckage, the investigation was not able to determine whether the pilot or passengers used the oxygen system. The investigation was unable to confirm whether the gas that was used to fill or replenish the aircraft's oxygen system met the specifications for aviators' dry breathing oxygen.

While it is unlikely that the oxygen bottle contained a gas other than aviators' dry breathing oxygen, this possibility could not be eliminated.

2.6 Warning systems and regulation

As hypobaric hypoxia took effect, the pilot's visual acuity and colour discrimination would have reduced, making the red warning lights even less likely to be noticed by the pilot. An aural warning was more likely to have been detected and acted upon by the pilot than a visual warning alone. An aural warning for high cabin altitude may also have gained the pilot's attention when the cabin altitude exceeded 10,000 ft, (see CAO 108.26 paragraph 1.6.3 of this report), well before he may have experienced significant effects of hypoxia. Had the visual warning system been set to provide the warning when the cabin pressure altitude exceeded 10,000 feet rather than 12,500 feet, and functioned normally, the pilot would have had more time to observe and react to the warning.

The pilot's lack of awareness of the unpressurised state of the aircraft suggested that the cabin altitude warning system did not alert the pilot to the situation. The investigation could not determine if the cabin altitude warning system functioned, or if it did, whether the pilot noticed the warning.

Safety critical warning systems for cabin altitude need to be effective to alert flight crews to a failure of the pressurisation system or its incorrect configuration. Visual warnings supported by aural alerts are more effective that visual warnings alone and CAO 108.26 also, "strongly recommended" an aural warning. In October 1999, the ATSB (IR19990155) recommended that the Federal Aviation Administration, as the certifying authority of the aircraft, consider the incorporation of an audible warning to operate in conjunction with the cabin altitude alert system on Beech aircraft and other aircraft so equipped. In March 2000, the Federal Aviation Administration (FAA) responded, in part:

> Although it is recognized that adding an aural warning is a desirable enhancement of the system, requiring such a warning for the existing fleet is not considered necessary to meet the minimum airworthiness standards.

The ATSB considered the FAA response and did not accept the response as adequate.

The ATSB made a similar recommendation to the Civil Aviation Safety Authority, which was accepted on 28 January 2000.

ATSB report 199902928, issued in December 2000, published a number of the recommendations issued to CASA covering the subject of oxygen systems in aircraft and associated regulatory requirements. A summary of these and CASA's responses are highlighted in the safety action section, Part 4, of this report.

2.7 Air traffic services response

When the pilot made his last intelligible transmission at 1032:59, the controller had no obvious indication that the pilot may have been impaired. The first indication the controller had of the pilot's impaired state was the series of open microphone transmissions. By then, the pilot was incapable of formulating and carrying out an appropriate response, as evidenced by his failure to level the aircraft at the assigned altitude, and his failure to respond to ATS instructions to select the IDENT function on his transponder.

3 CONCLUSIONS

Due to the limited evidence available, it was not possible to draw definitive conclusions as to the factors leading to the incapacitation of the pilot and occupants of VH-SKC.

3.1 Findings

1. The pilot was correctly licensed, had received the required training, and there was no evidence to suggest that he was other than medically fit for the flight.
2. The weather conditions on the day presented no hazard to the operation of the aircraft on its planned route.
3. The flightpath flown was consistent with the aircraft being controlled by the autopilot in heading and pitch-hold modes with no human intervention after the aircraft passed position DEBRA.
4. After the aircraft climbed above the assigned altitude of FL250, the speech and breathing patterns of the pilot, evidenced during the radio transmissions, displayed changes consistent with hypoxia.
5. Testing revealed that Carbon Monoxide and Hydrogen Cyanide were highly unlikely to have been factors in the occurrence.
6. The low Carbon Monoxide and Cyanide levels, and the absence of irritation in the airways of the occupants indicated that a fire in the cabin was unlikely.
7. The incapacitation of the pilot and passengers was probably due to hypobaric hypoxia because of the high cabin altitude and their not receiving supplemental oxygen.
8. A rapid or explosive depressurisation was unlikely to have occurred.
9. The reasons for the pilot and passengers not receiving supplemental oxygen could not be determined.
10. Setting the visual alert to operate when the cabin pressure altitude exceeds 10,000 ft and incorporating an aural warning in conjunction with the visual alert, may have prevented the accident.
11. The training and actions of the air traffic controller were not factors in the accident.

3.2 Significant factors

1. The aircraft was probably unpressurised for a significant part of its climb and cruise for undetermined reasons.
2. The pilot and passengers were incapacitated, probably due to hypobaric hypoxia, because of the high cabin altitude and their not receiving supplemental oxygen.

4 SAFETY ACTION

Local safety action

Subsequent to the accident, Airservices Australia amended the In Flight Emergency Response Checklist to incorporate procedures to be followed by air traffic controllers, when a controller suspects that a pilot has been affected by hypoxia.

ATSB safety action

During the course of the Australian Transport Safety Bureau investigation into a Beechcraft King Air 200 depressurisation incident, BO/199902928, three recommendations were issued by the ATSB on the subject of oxygen systems including cabin alert aural warning systems. One of these, issued on 28 July 1999, (IR19990084) recommended that the Civil Aviation Safety Authority issue a directive for an immediate check of the fitment of passenger oxygen system mask container doors on all Australian Beech King Air B200 aircraft and, all other aircraft similarly equipped.

On 16 September 1999, the Civil Aviation Safety Authority responded that it had issued an advisory letter to all Certificate of Registration holders of Raytheon pressurised twin-engine aircraft. The letter strongly recommended checking each passenger oxygen system mask container door for correct installation, but did not make such a check mandatory. CASA also issued Airworthiness Advisory Circular AAC 1-112 on the subject.

The final report contained additional recommendations on the same subjects.

Recommendation R20000288, issued on 17 December 2000 stated:

> The ATSB therefore recommends that CASA mandate the fitment of aural warnings to operate in conjunction with the cabin altitude alert warning systems on all Beechcraft Super King Air and other applicable aircraft.

The Civil Aviation Safety Authority's response dated 2 February 2001 stated:

> The Civil Aviation Safety Authority accepts this recommendation and will move to prepare a regulatory amendment to make it mandatory for pressurised aircraft to have aural cabin altitude alert warning systems. This amendment will follow the normal regulatory development process which, in the first instance, will lead to the circulation of a Discussion Paper. It is anticipated that the paper will be released this month.

On the 2 February 2001, the Civil Aviation Safety Authority also issued a Draft Discussion Paper, DP 0102CS, to the Australian aviation industry. The discussion paper was titled Proposal for Aural Warning to Operate With Cabin Altitude Alert Warning Systems. The discussion paper indicated that it was CASA's preferred option to mandate requirements to modify the aircraft concerned to install an audible warning to complement the existing cabin altitude alert warning system. Responses to that paper were to be provided to CASA by the 12 March 2001.

On the 15 February 2002, the ATSB received information from CASA indicating that development of a Notice of Proposed Rule Making (NPRM) on the fitment of aural warnings had been progressed, and that the NPRM was currently in the final stages of development prior to its expected release.

Recommendation R20000289, issued on 17 December 2000 stated:

> The ATSB recommends that CASA advise relevant operators of its interpretation of CAO 108.26 in relation to the applicability of the requirements for a device to provide the flight crew of pressurised aircraft with a warning whenever the cabin pressure altitude exceeds 10,000 feet.

The Civil Aviation Safety Authority's response dated 2 February 2001 stated:

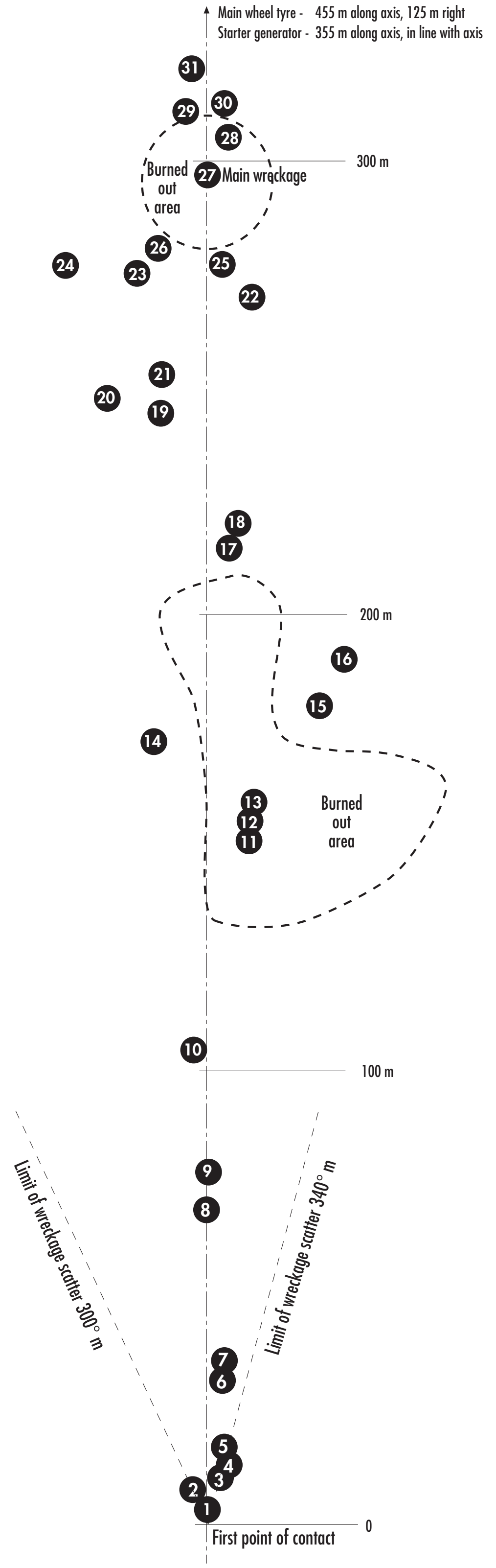
> The Civil Aviation Safety Authority accepts this recommendation and is now considering how best to clarify the intent of CAO 108.26, paragraph 3.1, for relevant operators.

The ATSB is monitoring the CASA action in regard to R20000288 and R20000289.

Investigation report BO/199902928 and the resultant recommendations are available on the Australian Transport Safety Bureau's Website, www.atsb.gov.au or from the Bureau on request.

ATTACHMENTS

Attachment A: Wreckage plot King Air VH-SKC 4 September 2000



Component

1	Wingtip light cover pieces
2	Wingtip fairing
3	Red navigation light cover pieces
4	Five propeller slashes
5	Left propeller blade
6	Three propeller slashes
7	Right propeller blade
8	Left aileron
9	Green navigaition light
10	Left propeller blade
11	Left propeller blade, two thirds
12	Horizontal stabiliser
13	Right aileron
14	Human body
15	Right propeller hub with two blades attached
16	Main landing gear strut and axle
17	Right wing outer section
18	Left wing, from root to mid outer (burned)
19	Human body
20	Human body
21	Pilot's seat
22	Nose gear tyre
23	Left propeller hub with one third of a blade attached
24	Right engine
25	Human body
26	Cabin door
27	Main wreckage
28	Left engine
29	Human body
30	Human body
31	Cabin door damper

Position of main wreckage: 18°05.3'S, 140°02.2'E

Elevation of main site: approx. 200 ft above sea level

Main wreckage consisted of burned remains of cockpit, fuselage, fin, rudder, right wing root and right landing gear strut. Two bodies were also located in the main wreckage.

Attachment B: Transcript of ATS communications with King Air VH-SKC 4 September 2000

Notes:

1. Only radio communications and ground coordination that are relevant to the occurrence involving VH-SKC have been transcribed.
2. All times are in UTC.
3. Altitudes are expressed as above mean sea level, rounded to the nearest hundred feet and are derived from radar data.

Legend:

The following abbreviations and symbols are used throughout this transcription:

SKC	Beech Super King Air 200 VH-SKC
ACD	Perth airways clearance delivery
SMC	Perth surface movement control
ADC1	Perth aerodrome control
PHD	Perth departures control
ML	Melbourne centre
?	Unidentified source
// //	Explanatory note inserted by transcriber
( )	Words open to other interpretation
…..	Significant pause (one dot per second)

Time	*VH-SKC altitude (ft)*	*From*	*To*	*Details*
10:03:16	On ground	SKC	ACD	Perth clearance delivery good aft.. evening this is Sierra Kilo Charlie for Leonora request airways.
		ACD	SKC	Sierra Kilo Charlie gooday cleared to Leonora via amended route Caspa then Debra planned route – maintain six thousand – Kajun three departure – squawk three three seven two
		SKC	ACD	That's Leonora via Caspa – oh sorry – amended route Caspa Debra then planned route – six thousand – Kajun three departure – code three five seven two
		ACD	SKC	Try three three seven two
		SKC	ACD	Yeah scrawly writing - three three seven two Sierra Kilo Charlie //humorous tone in voice//
		ACD	SKC	Sierra Kilo Charlie thanks.

10:04:29	On ground	SKC	SMC	Ground good evening this is Sierra Kilo Charlie Beech King Air for Leonora – received Quebec and we have eight POB – request taxi
		SMC	SKC	Sierra Kilo Charlie ground taxi to holding point bravo runway two one
		SKC	SMC	Holding point bravo runway two one Sierra Kilo Charlie
10:08:06	On ground	SKC	ADC1	Tower good evening Sierra Kilo Charlie ready runway two one
		ADC1	SKC	Sierra Kilo Charlie good evening line up
		SKC	ADC1	Line up Sierra Kilo Charlie
10:08:34	On ground	ADC1	SKC	Sierra Kilo Charlie contact departures airborne – cleared for takeoff
		SKC	ADC1	Departures airborne cleared for takeoff Sierra Kilo Charlie
10:10:28	1,000	SKC	PHD	Departures Sierra Kilo Charlie climbing to six thousand passing one thousand two hundred
		PHD	SKC	Sierra Kilo Charlie departures identified – climb to flight level one three zero
		SKC	PHD	Flight Level one three zero Sierra Kilo Charlie
10:14:29	7,100	PHD	SKC	Sierra Kilo Charlie contact Melbourne Centre one three three decimal niner gooday
		SKC	PHD	One three three decimal niner Sierra Kilo Charlie gooday
10:14:44	7,500	SKC	ML	Melbourne Centre good evening Sierra Kilo Charlie on climb Flight Level one three zero
		ML	SKC	Sierra Kilo Charlie Melbourne Centre good evening can you reach flight level one six zero by three six DME
		SKC	ML	Sierra Kilo Charlie affirm
		ML	SKC	Sierra Kilo Charlie roger climb to flight level two five zero with requirement to reach flight level one six zero by three six DME. I will be able to track shorten you when you are above sixteen thousand
		SKC	ML	Flight level one six zero by three six DME and cleared to flight level two five zero Sierra Kilo Charlie
10:20:12	15,600	ML	SKC	Sierra Kilo Charlie cancel SID recleared direct now to ah Debra
		SKC	ML	Cancel SID recleared direct Debra Sierra Kilo Charlie

10:32:54	25,600	ML	SKC	Sierra Kilo Charlie verify altitude
10:32:59	25,700	SKC	ML	Sierra Kilo Charlie – um – standby
10:33:25	25,900	ML	SKC	Roger higher levels are available if requested
10:34:22	26,500	ML	SKC	Sierra Kilo Charlie at this stage you're operating in block between flight level two five zero and flight level two seven zero advise intentions
10:34:45	26,700	SKC		//Open microphone transmission – duration 6 seconds//
10:34:52	26,800	ML		There is carrier wave only on one three three niner. If that is Sierra Kilo Charlie contact me now one two five decimal two
10:35:07	26,900	SKC		//Open microphone with one unintelligible word, then heavy breathing –duration 15 secs//
10:35:22	27,000	ML		There is a station transmitting on one three three nine with an open mike Sierra Kilo Charlie contact me now on one two five decimal two
10:35:31	27,000	SKC		//Open microphone – duration 4 seconds//
10:35:42	27,100	SKC		//Open microphone with heavy breathing – duration 34 seconds//
10:36:10	27,300	ML	SKC	you are not talking loudly open mike ???
10:36:20 10:36:25	27,300 27,300	ML ML	 SKC	Would all stations on frequency please standby one Sierra Kilo Charlie Sierra Kilo Charlie Melbourne Centre
10:36:50	27,500	SKC		//Open microphone with heavy breathing – duration 54 seconds//
10:37:20	27,700	SKC		//Open microphone with heavy breathing – duration 22 seconds//
10:38:30	28,100	ML	SKC	Sierra Kilo Charlie Sierra Kilo Charlie Melbourne Centre
10:38:45	28,200	SKC		//Open microphone with heavy breathing – duration 6 seconds//
10:38:55	28,300	SKC		//Start of open microphone with heavy breathing, continues till 10:42:50) //
10:39:12	28,500	ML	SKC	Sierra Kilo Charlie if receiving this transmission squawk ident
10:40:40	28,900	ML	SKC	Sierra Kilo Charlie Sierra Kilo Charlie Melbourne Centre if receiving this transmission squawk ident
10:41:01	29,000	ML	SKC	Sierra Kilo Charlie Sierra Kilo Charlie Melbourne Centre

10:41:41	29,200	ML	SKC	Sierra Kilo Charlie only receiving open mike from you. Would you contact me on one two five decimal two
10:42:50	29,500	SKC		// End of open microphone transmission – duration 233 seconds//
10:43:34	29,700	ML	SKC	Sierra Kilo Charlie Sierra Kilo Charlie Melbourne Centre one three three decimal niner frequency if monitoring this channel squawk ident
10:45:58	30,300	ML	SKC	Sierra Kilo Charlie Sierra Kilo Charlie Melbourne Centre if receiving this transmission squawk ident

The transmission from 10:38:55 until 10:42:50 was the last recorded from VH-SKC.

Attachment C: Analysis of the pilot's speech and related behaviour during the occurrence

Overview

During the investigation, the ATSB requested two independent analyses of the pilot's speech and related behaviour during the accident flight. The first analysis was conducted by a team from the US National Transportation Safety Board (NTSB). The team had previous experience in conducting voice analyses during investigations that examined the effects of issues such as stress, alcohol and medical impairment on a person's speech. The second analysis was conducted by a team of two forensic phoneticians based in Australia.

Both consultant teams were provided with copies of the following communications:

- communications between the pilot and air traffic control on the accident flight,
- communications by the same pilot in the same aircraft on a previous flight (30 August 2000), and
- communications between another pilot in another Beech Super King Air 200 and air traffic control on a flight conducted in June 1999, in which the pilot was known to have experienced hypobaric hypoxia. (ATSB 199902928).

Both consultants were asked to conduct an analysis of the pilot's speech on the accident flight, using the pilot's speech on the 30 August 2000 flight for comparison if required. They were also asked to compare the speech performance of the pilot on the accident flight with that of the pilot of occurrence 199902928.

The two analyses were conducted simultaneously and independently using different approaches.

The effects of hypoxia on speech

As part of their analysis, the NTSB team conducted a review of previous research and accident reports that have documented the effects of hypoxia on speech and related performance. The rest of this section outlines their findings in this area.

> A small amount of literature is available on the speech effects of hypoxia that includes evidence from both aviation accidents and laboratory research.
>
> One of the most interesting aspects of the literature, with regard to the present effort, is a series of reports from previous aviation accidents indicating that pilots can respond to hypoxia by keying the microphone without speaking. For example, in a 1998 accident in the United States (NTSB, 1998), a pilot, flying at 27,000 feet, advised air traffic control that he had lost cabin pressurization and needed an immediate descent. He received clearances to lower altitudes and "shortly after the pilot acknowledged the lower altitudes, the radio communications deteriorated to microphone clicks with no carrier."
>
> Japanese investigators provided a similar report, along with a description of several speech effects related to suspected hypoxia, in the investigation of a military mishap (Saito, 1980). The paper noted changes in the pilot's radio responses when he voiced required callouts as part of a military formation:
>
> "The delay of reaction time has also revealed the following: in replying to the leader after #2 wing man, the #3 pilot [the accident pilot] voiced "three" several times during flight, and the mean interval duration between #2 and #3

was 0.518 seconds (0.29 to 0.60) [in the early part of the flight]…After 21 minutes, the interval was prolonged to 3 seconds; at the last, there was no voice even though the mike was activated" (p. 403).

Finally, a 1991 Russian textbook (Ponomarenko, 1991) provided a specific description of several speech effects attributed to hypoxia (based on a study of military mishaps) that included a similar report:

"There is less speech exchange, then speech stops completely. There is increased response time to the controller. There is increased time with no response from 0.2-0.3 seconds up to 8 seconds and then also the interval after speech, until the pilot releases the microphone key, increases from 0.1-0.2 to 3-4 seconds as hypoxia develops. There is a decreased speed of speech, from 6 syllables per second down to 3 syllables per second. There are multiple cases where the radio goes on but the person does not say anything. Normally this occurs about 1-2 minutes before loss of consciousness (p. 52) [translated from Russian]."

Based on these reports, one symptom consistently associated with suspected hypoxia impairment was a tendency for the pilot to activate the microphone without speaking. Additional cited symptoms included delaying of response time to radio transmissions, a slowing of speech, and a slowing of the pilot's coordination of microphone pressing/speaking in which the pilot allows more "dead" time on the radio channel before and after speaking.

Slowing of speech has appeared as a symptom of alcohol impairment (NTSB, 1990, Johnson, 1990; Brenner, 1991) and medical impairment (suspected heart attack; NTSB, 1992), and slowing has been shown to affect both running speech that involves thinking and well-rehearsed phrases like the call sign.

Hypoxia has been associated with a "slurring" of speech (NTSB, 1982), and the available literature provides several measures that may capture aspects of articulation involved in "slurring." For example, there is evidence that hypoxia may degrade a speaker's voice onset time (VOT) (Lieberman, 1995; Lieberman, 1994). This is a subtle aspect of pronunciation that can especially affect the perceived clarity of certain sounds (i.e. the unvoiced consonants "p," "t," and "k" can be confused with the respective voiced consonants "b," "d," and "g," in English if the VOT is not precise). There is evidence that spectrographic displays may depict articulation changes caused by hypoxia (Saito, 1980; Government of Japan, 1987; Milovanovic, 1993). These include "blurred formations of formant, fundamental, and harmonic frequencies" and an "obscured gap" between separate vocalizations (Saito, p. 402). Articulation changes have been discussed for chemical impairment (Shuy, 1993) and documented for alcohol impairment (Johnson, 1990; Pisoni, 1989). Those shown for alcohol impairment appear to have reflected a deterioration in the motor coordination needed to produce difficult sounds, and included deletion or misarticulation of /r/ and /l/ (e.g. /r/ became /w/), final devoicing (e.g. /iz/ became /is/), and deaffrication (e.g. 'church' became 'shursh') (Johnson, 1990). There was also evidence of a misarticulation of /s/ as /Ú/ ('sh") which might be a unique phonetic correlate of alcohol impairment since the /Ú/ sound is actually more difficult to produce (Johnson, 1990). The articulation changes shown for alcohol impairment have not been tested for hypoxia.

Regarding other speech correlates of hypoxia, Schultz (1976) reported that exposure to high altitude did not affect several aspects of speech including fundamental frequency, variability of fundamental frequency, intensity, and shape of the speech envelope. Johannes (2000, p. A62) also found that exposure to high altitude did not affect fundamental frequency, while two accident investigations reported that fundamental frequency was unchanged (Government of Japan, 1987) or decreased (Saito, 1980) in situations of high altitude exposure. One author suggested that a symptom of hypoxia may be that the pilot fails to show an increased fundamental frequency when it might be expected in an emergency situation (Saito, 1980). Fundamental frequency has been shown to increase in response to psychological stress (Johannes, 2000; NTSB, 1999; Brenner, 1994; Brenner, 1996),

Finally, several reports indicated that hypoxia may cause deterioration in the quality of thinking reflected in speech, such as a pilot requesting a non-existent route (NTSB, 1997) or having difficulty recalling the identity of the air traffic facility (Government of Japan, 1987).

NTSB speech analysis for the accident flight

The NTSB team used the variables identified in their literature review as a basis to analyse the speech performance of the pilot during the accident flight. The team found that the pilot's last intelligible transmission at 1032:59 was found to differ from his previous transmissions in a number of ways. Nothing unusual was identified in any of the transmissions prior to 1032:59.

The results for several quantitative measures of speech are presented in Table 1. In total there were 15 speech samples on the 30 August 2000 flight and 15 speech samples from the pilot prior to the last intelligible response (at 1032:59) on the accident flight. The number of useful or measurable samples differed for each variable.

Table 1:
Quantitative measures of speech reported in the NTSB analysis for the accident flight and flight on 30 August 2000

Variable	*30 August 2000*	*Accident flight* Prior to 1032:59	*Accident flight* 1032:59
Response time to ATC (seconds)	1.6 (n=10, range 0.9 - 3.1)	1.6 (n=10, range 0.8 - 3.5)	3.6*
Time between keying microphone and speaking (seconds)	0.3 (n=15, range 0.1 - 0.9)	0.2 (n=13, range 0.0 - 0.6)	1.2*
Time between finishing speaking and finishing keying microphone (seconds)	0.2 (n=14, range 0.1 - 0.6)	0.2 (n=13, range 0.0 - 0.3)	0.3
Speaking rate: all speech (syllables/second)	7.0 (n=15, range 3.8 - 10.0)	7.1 (n=15, range 5.1 - 10.3)	3.3*
Speaking rate: call sign only (syllables/second)	9.4 (n=12, range 8.0 - 10.6)	9.5 (n=13, range 8.0 - 11.9)	8.2
Fundamental frequency [voice pitch] (Hertz)	117.7 (n=12, range 107 - 142)	121.6 (n= 13, range 109 - 143)	129
VOT for unvoiced consonant "k" in "kilo" (milliseconds)	54 (n=9, range 40 - 64)	50 (n=12, range 33 - 69)	94*

Note: An asterisk (*) indicates that the difference between the pilot's speech/behaviour at 1032:59 and the other samples was statistically significant (using Z scores, probability of difference due to chance was less than .05).

In addition to these quantitative measures, the NTSB reported the following qualitative results:

- Spectrogram patterns: The spectrogram[8] of the pilot's statement of the call sign at 1032:59 differed to the spectrograms of three other samples during the accident flight (including the last sample before 1032:59) and two samples from the flight on 30 August 2000. According to the NTSB report, the 'gaps between different words were not as evident, and the running characteristic patterns for different sounds (formants) were not as clearly formed'.
- Misarticulation of difficult sounds: The NTSB team subjectively judged that the pilot's statement at 1032:59 sounded imprecise in pronunciation compared to earlier statements. The pilot appeared not to articulate the /l/ in "charlie" although it was articulated in all other samples, to misarticulate the /ch/ in "charlie" more like /sh/ although it was articulated in all other samples, and to misarticulate the /r/ in "sierra" more like /w/ although it was more clearly articulated in several other samples.
- Completeness of response: The pilot's statement at 1032:59 was a deferral, and did not provide an answer to a request that was relatively easy to comply with. All previous responses by the pilot were meaningful responses to a controller's request. Further, the pilot did not act on the information provided by the controller since the aircraft continued to climb despite the controller having drawn attention to its altitude.

The NTSB team concluded that the results provided significant evidence of pilot impairment. The impairment was evident at 1032:59, but there was no evidence of impairment in the transmission prior to this one at 1020:12. The differences that were noted between the 1032:59 transmission and the pilot's previous transmissions had all been reported in the research literature as symptoms of impairment by hypoxia. The team also concluded the following:

> In summary, speech/breathing evidence indicates that the pilot experienced a rapid impairment, first shown in his statement at 10:32:57 (59), which led to an inability to respond in as few as four minutes. The details of the impairment are consistent with what is known about the effects of hypoxia.

NTSB analysis of pilot behaviour on the accident flight

In addition to analysing the pilot's speech on the accident flight, the NTSB team also analysed other aspects of the pilot's behaviour following the last intelligible transmission at 1032:59. The behaviour included the intermittent keying of the microphone and transmission of loud breathing sounds from 1034:41 to 1042:46.

The NTSB team's report noted that the pilot's last vocal response, at 1035:02, was unintelligible. The response time was 10.4 seconds. The time between keying the microphone and speaking was 0.5 sec, and the time between finishing speaking and finishing keying the microphone was 12.4 seconds.

The NTSB team noted that the tendency to key the microphone without speaking may be a characteristic symptom of hypoxia. They stated that the phenomena may suggest that pilots in the early stages of hypoxia impairment may be aware of a requirement to respond but may be too impaired to frame an intelligible response.

---

8 A spectrogram provides a running visual display of speech, plotting the amount of energy at different frequencies over time.

In terms of the breathing, the NTSB team noted that although the data were limited by the irregularity of the transmissions, it was evident within the available evidence that the pilot's breathing was irregular. More specifically, there was a pattern of alternation between apnea (no breathing) and hyperventilation (breathing abnormally fast) during the 8-minute period. The NTSB report also stated the following:

> Such periodic breathing irregularities (known as "Cheyne-Stokes" irregularities) are typically observed during comatose states resulting from mild brain damage, such as following a stroke. However, periodic breathing has also been observed to result from hypoxia (Ghazanshahi, 1993), both in the sleeping patterns of climbers and healthy subjects at high altitude (Mizuno, 1993; Salvaggio, 1998) and among conscious subjects experiencing high altitude in test chambers (Salvaggio, 1998; Waggoner, 1984; Lhoo, 1982) and airplanes (Busch, 2000). Since the pilot may have been conscious during part of the time that he displayed periodic breathing, hypoxia offers one of the few explanations documented in available medical literature that may account for the observed breathing irregularities.

NTSB speech analysis of occurrence 199902928

The NTSB team used the same methodology as they used for the accident flight analysis. The pilot of the aircraft on 21 June 1999 made seven transmissions prior to being overcome by hypoxia. He then made three further transmissions after recovering. The pilot's last intelligible transmission before being overcome, at 0559:52, was found to differ from his other transmissions in a number of areas. The results for several quantitative measures of speech are presented in Table 2. The number of useful or measurable samples differed for each variable.

Table 2:
Quantitative measures of speech reported in the NTSB analysis for the occurrence 199902928 flight (21 June 1999)

Variable	*Statements before and after 0559:52*	*0559:52*
Response time (seconds)	2.2 (n=6, range 1.7 – 3.0)	6.0*
Time between keying and before speaking (seconds)	0.5 (n=7, range 0.3 - 1.1)	1.0
Time between finishing speaking and finishing keying (seconds)	0.2 (n=8, range 0.1 - 0.4)	0.4
Speaking rate: all speech (syllables/second)	5.8 (n=8, range 4.0 – 8.0)	3.9
Speaking rate: call sign only (syllables/second)	6.7 (n=9, range 5.0-9.0)	3.6
Fundamental frequency (Hertz)	112.1 (n=8, range 100 - 134)	155*

Note: An asterisk (*) indicates that the difference between the pilot's speech/behaviour at 0559:52 and the other samples was statistically significant (using Z scores, probability of difference due to chance was less than .05).

A VOT measure could not be obtained for the pilot's transmission at 0559:52.

In addition to these quantitative measures, the NTSB team reported the following qualitative results:

- Spectrogram patterns: The spectrogram of the pilot's statement of the call sign at 0559:52 showed evident gaps between sounds and crisp definition of harmonics, suggesting that pronunciation was normal.
- Misarticulation of difficult sounds: The NTSB team judged that the pilot's statement at 0559:52 sounded "giddy" or "euphoric" when contrasted with the more "matter of fact" tone of other transmissions, but it did not necessarily sound imprecise in pronunciation. No consistent misarticulations were observed for the call sign at 0559:52 when contrasted with other call sign articulations on the sounds /t/ in "tester" and "two," /r/ in "tester" and "zero," and /s/ in "tester."
- Completeness of response: The pilot's response at 0559:52 was adequate but relatively incomplete in that the pilot did not acknowledge or explain why the airplane deviated from its track. (The response was also incorrect since the airplane continued to drift after his response). The pilot's other responses, by contrast, appeared focused and complete.

The NTSB team concluded that the differences in speech in the 0559:52 transmission relative to this pilot's other transmissions were similar to the results found for the accident flight. However, the pilot did not appear to misarticulate his speech and there was a clear increase in fundamental frequency.

The NTSB team concluded that the differences in the results for the accident flight and the occurrence 199902928 flight do not necessarily mean that the two pilots were exposed to different types of impairment. Their report noted that 'both responses seem within the range of effects reported for hypoxia, and the individual differences shown by these pilots could reflect personal reactions, differences in history and level of exposure to hypoxia, and other factors'.

Forensic phonetician's speech analysis of the accident flight

The forensic phonetician team conducted an analysis of the pilot's speech and related behaviour from a different perspective and using different measurement tools relative to the NTSB team. They had no aviation experience, and simply examined the pilot's speech for any obvious changes or other salient issues.

The team initially conducted an 'auditory' or qualitative analysis of the pilot's speech. They noted that the pilot's speech in the 1032:59 transmission sounded different from his other transmissions on the accident flight and his transmissions on the previous flight (30 August 2000). The 1032:59 transmission had the following qualities (which were not present in the other samples):

- Less clearly articulated. For example, the voiced dental stop (/d/) in the word "standby" was not pronounced. Although not unusual in natural speech, it was different from the pilot's other utterances of this word.
- Noticeable hesitancy in completing the utterance, with the continuity or fluency of the utterance being interrupted by a filled pause ("umm").
- Discernible jitter (irregular perturbations of fundamental frequency) throughout the entire utterance.

The team concluded that these qualities were suggestive of the pilot's attention being focussed elsewhere or of his experiencing some difficulty in the cognitive and/or neuromuscular processes of completing the utterance. They also conducted some acoustic or quantitative measures of the speech. Some of these measures are presented in Table 3. The 'articulation rate' referred to the number of syllables per second, after discounting any silent pauses in a speech sample.

Table 3:
Quantitative measures of speech reported in the forensic phonetician team's analysis for the accident flight and the flight on 30 August 2000

Variable	*30 August 2000*	*Accident flight: Prior to 1032:59*	*Accident flight: 1032:59*
Fundamental frequency (Hertz)	116.5	122.2 (n=4, range 111 – 124)	139* (n= 15, range 105 –140)
Speaking rate: all speech (syllables/second)	6.7	7.0 (n=4, range 4.8 – 7.7)	3.4* (n=15, range 4.9 – 10.4)
Articulation rate: all speech (syllables/second)	6.7	7.1 (n=4, range 4.8 – 7.7)	4.5* (n=15, range 5.2 – 10.4)

Note: An asterisk (*) indicates that the difference between the pilot's speech/behaviour at 1032:59 and the other samples was statistically significant (using Z scores, probability of difference due to chance was less than .05).

In addition, the team examined the formant of F-patterns[9] in the speech samples. Unfortunately, an analysis of only F2[10] was possible whereas an analysis of F1 to F4 is generally much more informative. To provide a standardised measure, the analysis was restricted to the pilot's utterance of the callsign in each speech sample. There was no difference between the samples on 30 August 2000 and the samples on the accident flight (excluding 1032:59). However, the 1032:59 sample differed from the other samples in some areas. The team described these as an 'undershoot' of some phonetic targets, which could be accounted for by some impairment of the speaker's neuromuscular control on that sample relative to the other speech samples.

Forensic phonetician team's speech analysis of occurrence 199902928

The team used the same methodology as per the accident flight analysis. They noted that the pilot's speech in the 0559:52 transmission sounded different from his six previous transmissions on the same flight. The 0559:52 transmission had the following qualities (which were not present in the other samples):

- Greater than expected prominence on both syllables of "tester", as well as the first syllable of "affirm".
- A discernible lack of continuity.

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9 An F-pattern analysis provides information about the resonant frequencies of the vocal tract, and changes in F-pattern reflect changes in the phonetic qualities of speech sounds. These qualities are perceived in speech as different vowels and consonants.

10 This restriction was due to limitations in the bandwidth of the recorded speech samples from between 250 Hertz to 2,350 Hertz.

The consultant concluded that as a result of these characteristics, the speaker sounded either distracted or disoriented.

The quantitative measures are presented in Table 4. The team's report also examined the formant of F-patterns in the speech samples. As with the accident flight, an analysis of only F2 was possible. Due to technical reasons, the analyses were restricted to the pilot's utterance of the words "nine" and "two" in the call sign. The F2 contours were found to be different in the 0559:52 sample relative to the other six samples. Overall, the consultant concluded that the irregularity of the F2 contours suggested that the pilot was experiencing some difficulty in controller articulatory gestures.

Table 4:
Quantitative measures of speech reported in the forensic phonetician team's analysis for the incident 199902928 flight

Variable	*Incident flight*	
	Prior to 0559:52	*0559:52*
Fundamental frequency (Hertz)	115.7 (n= 6, range 109 – 125)	140*
Speaking rate: all speech (syllables/second)	5.5 (n=6, range 3.8 – 6.4)	3.8*
Articulation rate: all speech (syllables/second)	5.8 (n=6, range 4.6 – 6.8)	3.8*

Note: An asterisk (*) indicates that the difference between the pilot's speech/behaviour at 1032:59 and the other samples was statistically significant (using Z scores, probability of difference due to chance was less than .05).

The team concluded that the analysis for the accident flight and the 21 June 1999 incident flight had 'striking similarities'. Although the pattern of F2 differences between the normal and abnormal speech was different in both cases, they could both be interpreted as a lack of neuromuscular control over articulator gestures in each case. The team reported that the consistencies in the results of the auditory and acoustic analysis of the two data sets, in which it was known that the pilot of one aircraft was experiencing hypoxia, suggest that hypoxia would be a plausible explanation for the within-speaker variations found in the speech of the pilot on the accident flight.

ATSB observations

The two analyses, conducted by independent teams using different measurement tools and methodologies, provided similar results and conclusions. The analyses concluded that the pilot's speech at 1032:59 was significantly different from his speech in any of the previous transmissions. The differences included the following:

- the pilot was slower to respond to the controller;
- the pilot keyed the microphone a relatively long time before speaking;
- the pilot spoke more slowly;
- the pilot's speech showed evidence of imprecise pronunciation, which was measured qualitatively and quantitatively;

- the pilot did not answer the controller's question or make an appropriate response; and
- the fundamental frequency of the pilot's voice was higher.

With the exception of the last variable, all of these differences have been noted in previous accident reports or research literature as effects of hypoxia. Previous reports and research have found that fundamental frequency[11] has not changed when exposed to altitude-related hypoxia. However, it should also be noted that both consultants found an increase in this variable on the occurrence 199902928 flight, in which the pilot was affected by hypobaric hypoxia. It could therefore be concluded that an increase of fundamental frequency is a possible, but not a necessary or typical, indication of exposure to hypoxia.

In conclusion, the pilot's speech and related behaviour at 1032:59 and after, showed significant signs of impairment, and the signs were consistent with the pilot being affected by hypoxia.

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11 In terms of the fundamental frequency measure, the NTSB team and the forensic phonetician's results were slightly different, with the latter finding a significant increase relative to previous transmissions whereas the NTSB team found it to be slightly higher than normal (but not a statistically significant difference). This difference in results may be due to the different software and techniques used by the two teams, or the fact that the NTSB team focussed only on the callsign whereas the other team measured the frequency across the whole utterance.

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Attachment D: Hypobaric hypoxia and depressurisation

The following is a description of the signs and symptoms that may occur in a subject who is affected by hypobaric hypoxia. It should be noted that signs and symptoms vary with individuals, and any one person may not experience all of them.

From FL150 to FL200 (15,000 to 20,000 ft) breathing air[12]:

Even in the resting subject, the symptoms and signs of hypoxia appear on acute exposure to altitudes greater than FL150 (15,000 ft) when breathing air. Higher mental processes and neuromuscular control are affected, and in particular there is a loss of critical judgement and will power. Usually there is no self-awareness of any deterioration in performance and hypoxia is not likely to be suspected. Thought processes are slowed, mental calculations become unreliable, and psychomotor performance is grossly impaired.

Light-headedness, visual disturbances, and tingling of the hands, feet and lips may be followed in severe cases by involuntary contractions of the muscles of the hands and face. The skin of the body and extremities may turn blue. There is decreased muscular co-ordination with loss of the sense of touch, so that delicate or fine movements are impossible.

Above FL200 (20,000 ft), breathing air[13]:

The symptoms in resting subjects become more pronounced as the altitude increases. Comprehension and mental performance decline rapidly, and unconsciousness may occur with little or no warning. Uncontrollable jerks of the arms often precede loss of consciousness, and convulsions may occur thereafter. Central and peripheral vision, colour vision, and visual acuity would all have been significantly degraded by hypoxia. Hearing can also be impaired by profound hypoxia.

In the event of a rapid decompression at FL250 (25,000 ft), the time of useful consciousness (TUC) is quoted as 270 +/- 96 seconds (approximately 3 to 6 minutes)[14]. Times of useful consciousness in most publications are considered to be overly optimistic and are unreliable.

Above 30,000 ft

Without the use of supplemental oxygen or an adequately pressurised cabin, continued flight above FL300 (30,000 ft) would result in the subject rapidly becoming unconsciousness, and in some cases, would result in death if the exposure persisted.

In this accident, the exposure time above FL300 (30,000 ft) was approximately 2 hours 15 minutes, and exposure above FL250 (25,000 ft) was approximately 3.5 hours. Such exposure would be sufficient to cause death in some individuals. A study[15] of 10 occurrences of stowaways riding in the wheel-wells of jet aircraft showed that

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12 Aviation Medicine, Third Edition. Edited by John Ernsting, Anthony N. Nicholson and David J.Rainford. Butterworth-Heinemann 2000 ISBN 0 7506 3252 6, p 55.

13 Aviation Medicine, Third Edition. Edited by John Ernsting, Anthony N. Nicholson and David J.Rainford. Butterworth-Heinemann 2000 ISBN 0 7506 3252 6, p 55.

14 Aviation Medicine, Third Edition. Edited by John Ernsting, Anthony N. Nicholson and David J.Rainford. Butterworth-Heinemann 2000 ISBN 0 7506 3252 6, Table 5-4, p 56.

15 Survival at High Altitudes: Wheel Well Passengers by Veronneau S.J.H., Mohler S.R., Pennybaker A.L., Wilcox B.C. and Sahiar F, published in the Aviation, Space and Environmental Medicine, Volume 67, No 8, August 1996

survival in a high-altitude, unpressurised environment is possible. Five stowaways survived unpressurised flights at altitudes as high as 39,000 feet. Another six stowaways perished either from a fall from the wheel well during the flight or from combined hypoxia/freezing. The report gave weight to the possibility of survival after extreme exposures and discussed cases of individuals who have been frozen and then progressively rewarmed during the descent. It suggested that a form of hibernation had occurred due to the lowered body core temperature at altitude that. may have increased the subject's chances of surviving acute hypobaric hypoxia.

Depressurisation

For the purposes of this report, a cabin depressurisation can be described as explosive, rapid or gradual. An explosive depressurisation occurs in less than 0.5 seconds, a rapid depressurisation lasts from 0.5 to 10 seconds and the time for a gradual depressurisation is greater than 10 seconds.

Following an event involving pressurisation, an aircraft may retain a small level of pressurisation, instead of being completely depressurised (0 lb/in^2 differential). However, with regard to the effect on occupants, a slightly pressurised aircraft has little difference from an unpressurised one.