Australian Government

Australian Transport Safety Bureau

AVIATION SAFETY INVESTIGATION
200303579

Cessna 404, VH-ANV
Jandakot Airport, WA

11 August 2003

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Front cover photo by George Canciani ©

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CONTENTS

INTRODUCTION

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

In terms of aviation, the ATSB is responsible for investigating accidents, serious incidents and incidents 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 transport 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 *Transport Safety Investigation Act 2003*. The object of an occurrence investigation is to determine the circumstances to prevent other similar events. The results of these determinations form the basis for safety action, including recommendations where necessary. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations.

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.

The 24-hour clock is used in this report to describe the local time of day, Western Standard Time (WST), as particular events occurred. Western Standard Time was Coordinated Universal Time (UTC) + 8 hours.

EXECUTIVE SUMMARY

On 11 August 2003, at about 1535 Western Standard Time, a Cessna Aircraft Company 404 Titan (C404) aircraft, registered VH-ANV, took off from runway 24 right (24R) at Jandakot Airport, WA. One pilot and five passengers were on board the aircraft. The flight was being conducted in the aerial work category, under the instrument flight rules.

Shortly after the aircraft became airborne, while still over the runway, the pilot recognised symptoms that he associated with a failure of the right engine and elected to continue the takeoff. The pilot retracted the landing gear, selected the wing flaps to the up position and feathered the propeller of the right engine.

The pilot later reported that he was concerned about clearing a residential area and obstructions along the flight path ahead, including high-voltage powerlines crossing the aircraft's flight path 2,400 m beyond the runway. The aircraft was approximately 450 m beyond the upwind threshold of runway 24R when the pilot initiated a series of left turns. Analysis of radar records indicated that during the turns, the airspeed of the aircraft reduced significantly below the airspeed required for optimum single-engine performance.

The pilot transmitted to the aerodrome controller that he was returning for a landing and indicated an intention to land on runway 30. However, the airspeed decayed during the subsequent manoeuvring such that he was unable to safely complete the approach to that runway. The pilot was unable to maintain altitude and the aircraft descended into an area of scrub-type terrain, moderately populated with trees. During the impact sequence at about 1537, the outboard portion of the left wing collided with a tree trunk and was sheared off. A significant quantity of fuel was spilled from the wing's fuel tank and ignited. An intense post-impact fire broke out in the vicinity of the wreckage and destroyed the aircraft.

Four passengers and the pilot vacated the aircraft, but sustained serious burns in the process. One of those passengers died from those injuries 85 days after the accident. A fifth passenger did not survive the post-impact fire.

The investigation assessed that the aircraft was below its maximum permitted take-off weight and within centre of gravity limits at the time of the accident. Analysis of radar data indicated that the aircraft was operating significantly below the optimum speed for maximum single-engine climb performance for most of the flight.

A number of factors affect an aircraft's one-engine inoperative performance, including any variation from the airspeed to achieve the one-engine inoperative best rate of climb, control inputs made by the pilot to manage the situation and the effect of manoeuvring/turning the aircraft. One-engine inoperative climb performance would have significantly reduced during the turns, with a loss of at least 25 per cent during a 10 degree angle of bank turn, 50 per cent during a 20 degree angle of bank turn and more than 90 per cent had there been a 30 degree angle of bank turn.

Examination of the right engine revealed a material anomaly with the sleeve bearing from the engine-driven fuel pump. That bearing exhibited evidence of localised adhesive wear (galling) that had restricted the rotation of the pump spindle shaft. The bearing had previously been replaced during the last engine overhaul. Analysis of the bearing revealed that it had been manufactured from material that possessed inferior galling resistance when compared with bearings from similar pumps. The investigation concluded that the specified material for the replacement sleeve bearing was inadequate with respect to its galling resistance. High torsional loads between the spindle shaft and the sleeve bearing had caused the pump's drive shaft to shear at a critical phase of flight. Associated with a loss of drive to the pump shaft was a reduction in fuel pressure, which was insufficient to sustain operation of the engine at take-off power.

Following the occurrence, the operator modified other C404 aircraft in its fleet to incorporate a warning light to indicate low fuel pressure. The ATSB has previously issued three recommendations (see ATSB report BO/200105618) relevant to pilot training for engine-out operations in multi-engine aircraft. Those recommendations are also relevant to the circumstances of this occurrence.

Records from the Fire and Emergency Services Authority of Western Australia (FESA) indicated that the first responding appliances reached the Jandakot Airport emergency gate, about 1,500 m from the accident site, at 1551:52, about 12.5 minutes after being notified by the police. The fire fighting vehicles were not able to track direct to the accident site and had to negotiate runways and bush tracks. The FESA records indicated that the first information from the accident site was received at 1558:28, which stated 'MT is tackling the fire, some persons are out, some persons are missing.'

Following an occurrence at Bankstown Airport in November 2003, the ATSB conducted an investigation at the direction of the Minister for Transport and Regional Services to '…investigate the effectiveness of the fire fighting arrangements for Bankstown Airport as they affected transport safety…'. Bankstown Airport is a General Aviation Aerodrome Procedure (GAAP) aerodrome that had similar provisions for aerodrome rescue and fire fighting services (ARFFS) to Jandakot Airport at the time of the occurrence involving ANV. The ATSB report (200305496) on that investigation is available on the ATSB web site www.atsb.gov.au

1 FACTUAL INFORMATION

1.1 History of the flight

On 11 August 2003, at about 1535 Western Standard Time, a Cessna Aircraft Company 404 Titan (C404) aircraft, registered VH-ANV, took off from runway 24 right (24R) at Jandakot Airport, WA. One pilot and five passengers were on board the aircraft. The flight was being conducted in the aerial work category, under the instrument flight rules (IFR).

The pilot recalled that both engines were operating at full power during the take-off roll and that the aircraft became airborne at an indicated airspeed of about 95 kts. As he reached to initiate retraction of the landing gear, he recalled applying left rudder to prevent the aircraft's nose from yawing to the right and interpreted that as a symptom of a failure of the right engine. He elected to continue the takeoff, retracted the landing gear and positioned the wing flap selector to the 'UP' position. The pilot recalled that the aircraft was about 50 ft above the runway at the time of the loss of engine power.

The pilot recalled looking at the right engine and observing the propeller slowing down. He moved the control lever for the right propeller to the 'feather' (see section 1.6.3) position and the propeller appeared to feather normally. He reported that, due to the aircraft's height above the ground, he did not have time to check engine instruments, confirm the engine failure using the throttle or complete other troubleshooting of the aircraft systems. He did not recall hearing any unusual engine noises and described the loss of engine power as 'gradual'.

Air traffic controllers in the tower recalled hearing a change in sound from the aircraft's engines when the aircraft was airborne, about 10 to 15 ft above the runway and just past taxiway Golf.[1] They recognised that sound as characteristic of the noise made during the simulation of an engine failure during training in a multi-engine aircraft. They did not recall hearing any other unusual noises from the engines, nor did they observe flames, smoke or fluid trailing the aircraft. The controllers used binoculars to monitor the aircraft after it became airborne. They recalled seeing the right engine's propeller slowing down and then rotating slowly in the airflow.

The aircraft was approximately 300 m past the upwind runway threshold and slightly right of the extended runway centreline, when the pilot broadcast to the controller 'I've got an emergency thanks, I'm going to have to come around'. Air traffic services (ATS) radar data indicated that at that time, the aircraft was about 100 ft above the aerodrome elevation.[2]

ATS radar data indicated that the aircraft commenced a left turn from a position approximately 450 m past the upwind runway threshold and at a recorded altitude of about 200 ft (see Figure 1).[3]

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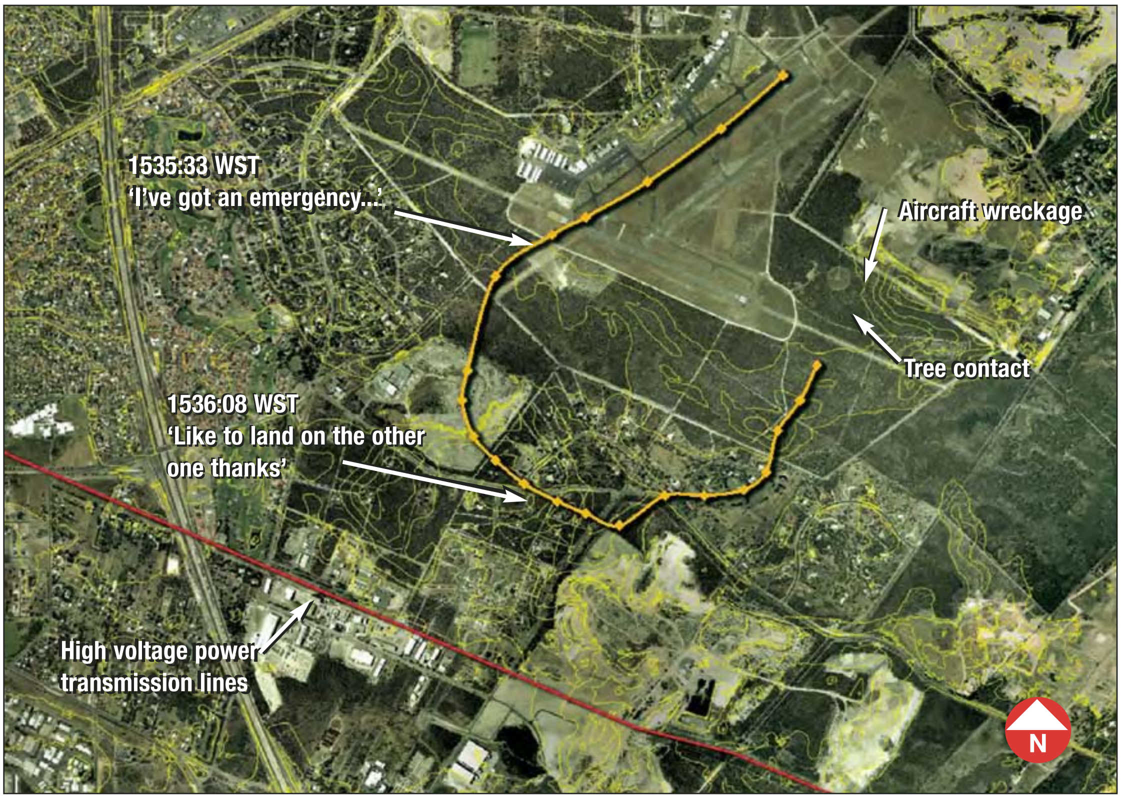
[1] Taxiway Golf was approximately 970 m from the threshold of runway 24R.

[2] ATS radar data is recorded to the nearest 100 ft.

[3] Airservices Australia publication, *En Route Supplement Australia*, stated that the aerodrome reference point was 99 ft above mean sea level, which is generally consistent with the elevation of the runways.

FIGURE 1: Aerial photograph[4] of Jandakot Airport with ATS radar data overlaid



During the crosswind leg of the circuit, the pilot broadcast to the controller 'Like to land on the other one thanks' and then, responding to a question, 'Ah the 12 (one two) there thanks'.[5] That was the last broadcast recorded from the pilot. The controller acknowledged the broadcast and cleared the aircraft to land.

Witnesses recalled that the aircraft started losing height as it flew downwind, with the nose pitching up as the aircraft descended. Some witnesses recalled hearing the noise from the operating engine and reported that they did not hear any misfiring or other indication that the engine was running abnormally. A large fireball was observed moments after the aircraft had disappeared from view at about 1537.

1.2 Injuries to persons

Injuries	*Crew*	*Passengers*	*Others*	*Total*
Fatal[6]	-	2	-	2
Serious	1	3	-	4
Minor	-	-	-	-
None	-	-	-	-

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[4] Aerial photograph reproduced with permission from the WA Department of Land Information, reference number P369.

[5] Runway 12 was the reciprocal of runway 30. Based on the aircraft's position at that time and the subsequent flight path, the investigation concluded that broadcast indicated the pilot's intention to make a landing on runway 30.

[6] While there were two fatalities as a result of the accident, it should be noted that, for statistical purposes, only an injury resulting in death within 30 days of the date of the accident is classified as a fatal injury by the International Civil Aviation Organization (ICAO). In this case, one passenger succumbed to his injuries after 85 days (see section 1.15.1).

1.3 Damage to aircraft

The aircraft and on-board equipment were destroyed by impact forces and post-impact fire.

1.4 Other damage

Other than damage to natural vegetation, there was no damage to property.

1.5 Personnel information

Type of licence	Commercial Pilot (Aeroplane) Licence
Medical certificate	Class 1
Flying experience (total hours)	16,722
Flying experience (multi-engine)	12,345
Hours in the preceding 30 days	18

Records from the Civil Aviation Safety Authority (CASA) indicated that the pilot held current approvals to provide multi-engine conversion training (non-turbine aircraft, below 5,700 kg). He was employed by the aircraft operator on a full-time basis. The pilot had previously held a position as chief flying instructor with a flying training organisation.

The pilot had completed a base check on 6 May 2003.[7] That check was performed by the chief pilot in the occurrence aircraft and included sequences required for the renewal of the pilot's Command Multi-Engine Instrument Rating. The test report form submitted to CASA, indicated that the pilot had satisfactorily completed simulated engine failures before and after decision speed[8], one-engine inoperative circuit and landing and other emergency sequences.

The pilot's logbook indicated that he had last flown on 9 August 2003. He had flown from Jandakot Airport for a number of years and was familiar with the aerodrome environment.

1.6 Aircraft information

Manufacturer	Cessna Aircraft Company
Model	C404 Titan
Serial number	4040820
Registration	VH-ANV
Year of manufacture	1981
Certificate of airworthiness	Issued 29 June 1995
Certificate of registration	Issued 1 June 1981
Maintenance release	Valid to 16,882.0 hours or 2 May 2004[9]
Total airframe hours	16,819.6 hours
Allowable take-off weight	3,810 kg
Actual take-off weight	Estimated 3,773 kg
Weight at occurrence	Estimated 3,773 kg
Allowable centre of gravity limits	4,321.5 to 4,548.6 mm
Centre of gravity at occurrence	Estimated 4,515 mm

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[7] CASA had issued the aircraft operator approval to perform training and checking of its pilots under Civil Aviation Regulation (CAR) 217. That required recurrent checking of each pilot employed by the operator.

[8] Decision speed may be defined as the speed at or above which, should an engine fail, the takeoff would be continued.

[9] Whichever occurred first.

1.6.1 Aircraft certification

The aircraft was manufactured in the United States of America and was certified as a normal category aircraft complying with the requirements of Federal Aviation Regulation 23 (FAR 23). FAR 23 did not require any assurance of take-off climb performance with an engine becoming inoperative during the take-off roll or initial climb.

1.6.2 Recent maintenance history

The aircraft was being maintained in accordance with a CASA-approved maintenance schedule. The last period of scheduled maintenance was completed on 2 May 2003. The aircraft's maintenance release was not recovered from the accident site. A report from the pilot of the previous flight indicated that there were no outstanding aircraft unserviceability issues.

1.6.3 Engine and propeller information

The aircraft was equipped with two GTSIO-520-M horizontally opposed, six cylinder, fuel-injected and turbocharged engines, rated to produce 375 horsepower at 2,235 propeller RPM and 40 inches Hg manifold pressure. The turbocharger was equipped with a waste gate to prevent 'overboosting'[10] of the engine when operated in accordance with the aircraft manufacturer's Aircraft Flight Manual (AFM).

The Aircraft Logbook indicated that the right engine was installed in October 2000, and had accumulated 1,353.3 hours operation since overhaul. Engine documentation indicated that a newly-overhauled engine-driven fuel pump was also fitted at that time. The engine manufacturer published a maximum time between overhaul of 1,600 hours.

The left engine was installed in December 2001 and had accumulated 513.7 hours operation since overhaul.

Each engine was equipped with a three-bladed, constant-speed propeller, driven from the engine crankshaft via a reduction gearbox. Pilot selection of the propeller control lever to the 'feather' position would alter the angle of the propeller blades to a position where they are approximately parallel to the oncoming airflow. That action would prevent the airflow from 'windmilling' the propeller, significantly reducing drag and optimising the aircraft's one-engine inoperative performance.

1.6.4 Fuel system information

Fuel was supplied to the engines from a fuel tank located in the outboard part of each wing. Each tank had a capacity of 651 L useable fuel. Each engine could be supplied with fuel from either tank, using a separate cockpit fuel selector. Fuel valves were mounted in each wing, and were controlled from the cockpit fuel selector by control rods, cables and gearboxes. A mechanical interlock prevented the inadvertent selection of each selector to the 'OFF' position.

Each engine was fitted with an engine-driven fuel pump (EDFP). The pump was driven from the engine's accessory drive by a sacrificial drive shaft[11]. Fuel from the EDFP was supplied to the fuel control unit for metering to the fuel injection nozzle for each cylinder. A fuel flow gauge provided information to the pilot about the amount of fuel being supplied to each engine.

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[10] Overboosting is the condition where pressure in the engine's induction system exceeds the design parameters, possibly resulting in engine damage. The operation of the waste gate permits full throttle movement without sustained overboosting of the engine.

[11] In the event of a pump malfunction that resulted in restriction of the rotation of the pump shaft, the drive shaft would shear and prevent damage to other parts of the engine's accessory gear drive.

Electrically-powered auxiliary fuel pumps provided a source of fuel pressure for engine start, the purging or suppression of fuel vapour[12] and also acted as a backup for each EDFP. The auxiliary fuel pumps could supply fuel at either low or high output pressure. The switching system for ANV's auxiliary fuel pumps had been modified in accordance with the aircraft manufacturer's service bulletin *MEB 88-3*. That modification removed an original system design feature which, with a loss of output pressure from the EDFP and the auxiliary fuel pump switched 'ON', would automatically switch the output of the auxiliary pump from low to high pressure.[13] The service bulletin indicated that direct pilot activation of the auxiliary fuel pumps in all modes was the most desirable and simplest mode of activation, and that those modifications were considered to be mandatory.

Post-modification, the activation of each auxiliary fuel pump was controlled by a three-position lever-lock toggle switch[14]. In the 'LOW' position, the pump provided supplemental fuel pressure. The AFM indicated that in the LOW position, the auxiliary pump would produce 5.5 psi of fuel pressure. The AFM required that the auxiliary pumps be selected to the LOW position during takeoff and landing and at other times as required to suppress fuel vapour.

In the event of a failure of the EDFP, the pilot could manually select the auxiliary fuel pump switch to 'HIGH' and that would provide fuel for partial-power engine operation. The AFM supplement incorporating *MEB 88-3* indicated that high output from the auxiliary fuel pump may not be sufficient for normal engine operation at high manifold pressure and high RPM. In that case, the supplement recommended reducing manifold pressure to a setting compatible with the indicated fuel flow. The supplement also noted that at low power settings, the mixture may have to be leaned to ensure smooth engine operation. The AFM supplement incorporating *MEB 88-3* included the following cautionary note:

> If the auxiliary fuel pump switches are placed in the HIGH position with the engine-driven fuel pump(s) operating normally, total loss of engine power may occur.

A mechanical interlock prevented the inadvertent selection of the pump switch to the HIGH position.

1.6.5 Quality of the fuel

The aircraft was parked undercover in the operator's hangar during the days prior to the occurrence. On the afternoon of the occurrence, the aircraft was moved to the parking apron where pre-flight refuelling was completed.

Civil Aviation Order (CAO) 20.2 required pilots to conduct an inspection of their aircraft's fuel system after each refuelling, which required the sampling of a quantity of fuel from each of the aircraft's tanks. The pilot reported that the post-refuelling samples from the aircraft's fuel system had the normal appearance of 'Avgas' and there was no visible sign of fuel contamination. Pilots of aircraft refuelled immediately before and immediately after ANV reported that their post-refuelling samples from their aircraft fuel systems had the normal appearance of Avgas and there was no visible sign of contamination.

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[12] Such as could be encountered at high ambient temperatures or at high altitude.

[13] A malfunction of the automatic switching system could result in either a loss of engine power due to over-fuelling of the engine (auxiliary fuel pump switching to high pressure and EDFP operating), or a lack of fuel pressure to sustain operation of the engine at the required power setting (failure of EDFP and failure of automatic switching system to detect that drop in fuel pressure).

[14] 'OFF', 'LOW' and 'HIGH'.

Due to the fire damage, it was not possible to obtain a post-accident sample of fuel from the aircraft's fuel system.

Following the occurrence a sample of fuel was obtained from the refuelling tanker from which the aircraft was refuelled prior to the flight. Analysis of that sample confirmed that the fuel was the correct grade and complied with relevant specifications for Avgas 100.

Fuel records revealed no discrepancy between meter readings and sequential copies of fuel delivery dockets, nor the quantity of fuel delivered by the refuelling tanker during the day of the accident.

The investigation therefore concluded that the quality or type of fuel on board ANV was not a factor in the occurrence.

1.6.6 Aircraft flight controls & associated systems information

The aircraft's flight controls consisted of ailerons, elevators and rudder and their respective trim systems. The pilot could use the trim system on each control surface to relieve the control loads experienced during flight.

Each engine was equipped with an engine-driven hydraulic pump that provided hydraulic pressure to operate the aircraft's wing flaps and landing gear. The wing flaps consisted of an inboard and outboard surface. With the flap selector positioned to 'T.O. & APPR.', the inboard flap surface extended 10 degrees and the outboard surface extended 8 degrees.

The AFM stated that at maximum engine RPM with both engines operating, the landing gear would complete its retraction cycle in about 4.5 seconds. A reduction in engine RPM or the loss of an engine driven hydraulic pump would increase the time required to complete the retraction cycle. The aircraft manufacturer advised that the retraction cycle would take approximately 8 seconds with one inoperative hydraulic pump. Operation of wing flaps during the retraction cycle increased the time required to retract the landing gear by about 0.4 of a second.

1.6.7 Aircraft operating weight

The operator's flight records indicated that the fuel tanks contained 160 lbs (104 L) of Avgas on completion of the previous flight. Prior to the occurrence flight, ANV was refuelled with an additional 650.5 L of Avgas.

The investigation calculated the aircraft's weight and balance using the basic empty weight and moment contained in the most recent weight and balance record sheet. The investigation adjusted that weight for changes to the aircraft configuration for the intended operation, the estimated fuel load[15], the reported weight of equipment loaded for the flight and the reported weights of the occupants.[16]

The investigation estimated that at the time of the occurrence the aircraft was operating below the maximum permitted take-off weight and within the stipulated centre of gravity limits.

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[15] 104 L recorded as remaining from the previous flight and 650.5 L loaded prior to the occurrence flight. 21 kg was allowed for start, taxi and takeoff.

[16] A number of variables may influence the accuracy of those weight calculations, including any discrepancy between the recorded and actual quantity of fuel in the aircraft tanks prior to refuelling, variations in the reported weights for persons on board the aircraft, variations in recorded equipment weights and the presence of unidentified items in the aircraft.

1.6.8 Aircraft equipment configuration

The aircraft hirer had temporarily installed specialised electronic and communications equipment on the aircraft that was mainly housed in two equipment cases. Those cases were installed one on top of the other on the left side of the passenger cabin. The lower equipment case was mounted on a frame secured to the seat rails along the floor of the cabin. The upper equipment case was secured to the lower case by webbing straps. Other associated equipment, such as laptop computers and radio communications equipment was distributed at other positions through the aircraft cabin.

1.7 Meteorological information

Data from the Bureau of Meteorology's (BoM) automatic weather station[17] (AWS) at Jandakot Airport indicated a south-westerly wind at a speed of about 10 kts at the time the aircraft took off. The temperature was 16 degrees C and atmospheric pressure was 1003 hPa.

The BoM analysed the information recorded by the AWS between 1534 and 1540; around the time of the flight. That analysis indicated a 1 to 2 kt variation in average wind speed and a maximum directional variation of 9 degrees.

The investigation concluded that the prevailing weather conditions were not a factor in the occurrence.

1.8 Aids to navigation

Not relevant to this occurrence.

1.9 Communications

Communications between ATS and the pilot were recorded by ground-based voice recording equipment. The quality of the recorded transmissions from the aircraft was good.

- 1526:26 pilot obtained airways clearance
- 1528:25 pilot reported taxiing
- 1533:00 pilot reported ready, runway 24R
- 1534:00 controller cleared pilot to line-up, runway 24R
- 1534:35 controller cleared pilot to takeoff
- 1534:39 pilot acknowledged take-off clearance
- 1535:33 pilot reported emergency to controller
- 1536:08 pilot reported intention to land on other runway
- 1536:12 pilot clarified, runway 12 (last recorded transmission from pilot of ANV)
- 1536:14 controller cleared pilot to land.

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[17] The AWS was located close to the aerodrome's primary wind direction indicator. Wind velocity was recorded at a height of 10 m (33 ft) above ground level.

1.10 Aerodrome information

1.10.1 General

The available runways at Jandakot Airport were:

- runway 06L/24R, which was sealed, 1,392 m long and 30 m wide
- runway 06R/24L, which was sealed, 1,150 m long and 18 m wide
- runway 12/30, which was sealed, 990 m long and 30 m wide.

At the time of the occurrence, runway 24R was in use for aircraft departing to the west.

An aerodrome control service was active at the time of the occurrence and General Aviation Aerodrome Procedures (GAAP) applied. Operational information about the aerodrome was promulgated to pilots in the *En Route Supplement Australia* (ERSA) and by Notice to Airmen (NOTAM).

1.10.2 Runway 24R information

Due to infringements on the required obstacle-clear approach slope, the landing threshold of runway 24R was permanently displaced 146 m, and the landing threshold of runway 06L (the reciprocal runway) was permanently displaced 119 m.

The take-off run available (TORA) for runway 24R corresponded to the physical length of the runway (1,392 m). The take-off distance available (TODA) was the physical length of the runway, plus 60 m of clearway[18] (1,452 m).

The accelerate-stop distance available (ASDA) for runway 24R corresponded to the physical length of the runway (1,392 m). The ERSA stated that when entering runway 24R at the intersection with taxiway Delta (as used by the pilot of ANV), all distances were to be reduced by 145 m. That resulted in an ASDA for the accident flight of 1,247 m and a TODA of 1,307 m. The elevation of the threshold of runway 24R was 94 ft and the runway slope was level.

The terrain beyond the upwind threshold was clear of obstructions and obstacles for a distance of 275 m. A cleared area, approximately 35 m wide, extended for an additional 250 m along the extended centreline of runway 24R, to the aerodrome boundary. Either side of that cleared area was scrub-type terrain, moderately populated with low trees. The terrain to the west of the aerodrome rose slightly.

1.10.3 Published obstacle-clear take-off climb gradients

Obstacle-clear take-off climb gradients were published in ERSA and provided pilots with information about the aircraft climb performance required to assure obstacle clearance from the critical obstacle along the take-off flight path. Those obstacles had been surveyed to a distance of 2,500 m from the upwind runway threshold. That information was provided to assist pilots with planning for various contingencies during takeoff. A NOTAM had amended the take-off gradients published in ERSA.

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[18] *Aeronautical Information Publication*, GEN 2.2 defined clearway as: A defined rectangular area on the ground or water under the control of the appropriate authority, selected or prepared as a suitable area over which an aeroplane may make a portion of its initial climb to a specified height.

That data indicated that the take-off flight path for runway 24R was clear of obstacles above a gradient of 2.8 per cent from the upwind threshold. Supplementary take-off distances, published in ERSA and the NOTAM, provided information about the TORA for other climb gradients. Those indicated that:

- 979 m of runway was available to an aircraft capable of achieving a 1.6 per cent climb gradient
- 1,153 m of runway was available to an aircraft capable of achieving 1.9 per cent climb gradient
- 1,281 m of runway was available to an aircraft capable of achieving 2.2 per cent climb gradient
- 1,377 m of runway was available to an aircraft capable of achieving a 2.5 per cent climb gradient.

1.10.4 Other flight path obstacles

The pilot recalled that following the engine failure he became concerned about the performance of the aircraft and its ability to clear houses upwind of the runway threshold and climb clear of high-tension powerlines along the aircraft's flight path. He assessed that maintaining runway heading, or initiating a right turn, would require flight over residential areas.

High-voltage powerlines crossed the extended centreline of runway 24R, approximately 2,400 m from the upwind threshold, and at an angle of about 120 degrees (see Figure 1). A powerline tower was close to the extended runway centreline and about 152 ft above the runway threshold elevation.

The chief pilot stated that, prior to the occurrence he had not considered the powerlines upwind of runway 24 as obstructions and would not have required those to be included as considerations in pre-takeoff safety briefing for runway 24.

1.11 Flight recorders

The aircraft was not fitted with a flight recorder or a cockpit voice recorder, nor was there any legislated requirement to do so.

1.12 Wreckage and impact information

1.12.1 General

The aircraft descended in approximately a wings-level attitude into an area moderately populated with trees that were about 6 m tall (see Figure 2). The descent angle, measured from the first evidence of contact with the tree canopy, to the point of ground impact, was about 6 degrees. The flight path at impact was about 025 degrees magnetic.

The outboard portion of the left wing collided with the trunk of a tree during the impact sequence and was sheared off. That impact ruptured the left fuel tank and spilled a significant quantity of fuel.

FIGURE 2: Initial impact with trees, looking back along the aircraft's flight path

The aircraft collided with several other trees during the impact sequence and there was evidence of significant damage to the leading edge of the wings and horizontal stabilisers. The fuselage came to rest with the cabin area intact, on a heading of approximately 290 degrees magnetic and about 20 m from where the fuselage initially impacted the ground. The wing flaps and landing gear were retracted (up) at the time of impact. The aircraft was consumed by the post-impact fire (see Figures 3 and 4).

The cockpit fuel selector for the left engine was found in the 'LEFT MAIN' position. The cockpit fuel selector for the right engine was found rotated clockwise from the 'RIGHT MAIN' position. Impact damage to the inboard leading edge of the right wing indicated that the cable linkage to the fuel selector valve could have been disrupted during the impact sequence.

Technical examination of the left and right fuel selector valves revealed them to be in the ON position, consistent with each engine being supplied fuel from its respective fuel tank. The emergency cross feed shutoff valves were open, indicating that fuel was available from the opposite main tank for the purpose of cross feed. This was the position for normal flight operations.

Technical examination of switch fragments from the left and right auxiliary fuel pumps confirmed that both switches were in the LOW position at the time of the post-impact fire (see Figure 5).

FIGURE 3: Forward aircraft cabin

FIGURE 4: Cockpit area

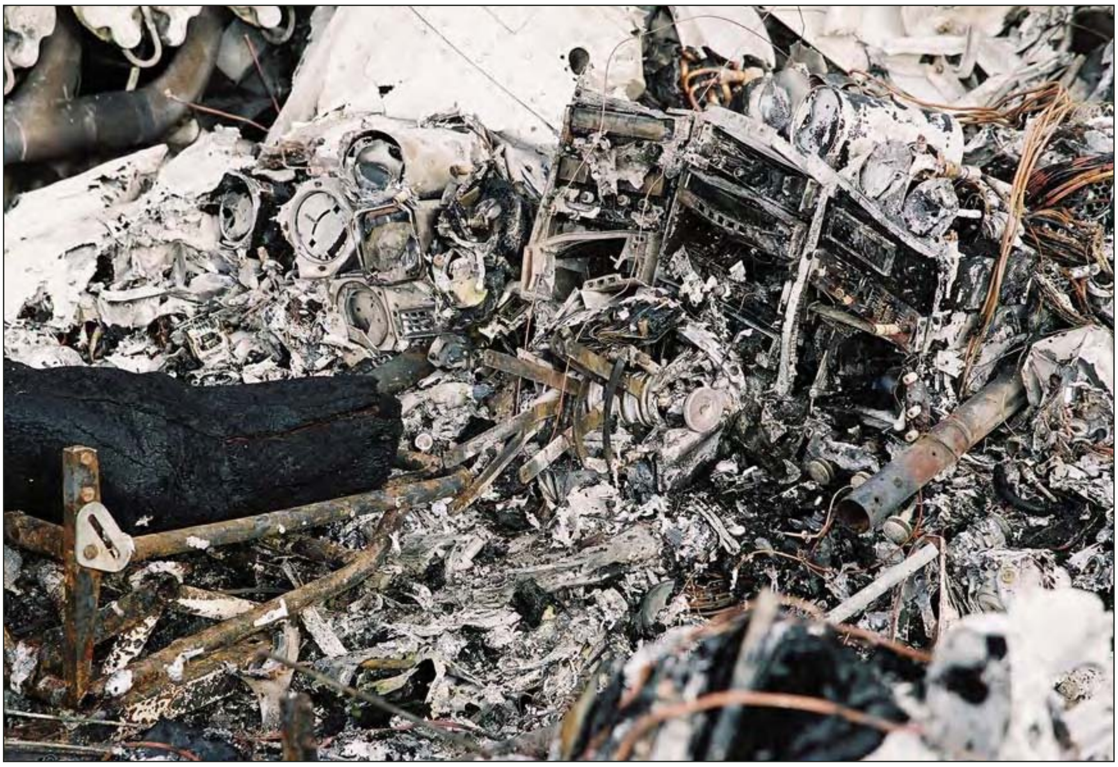
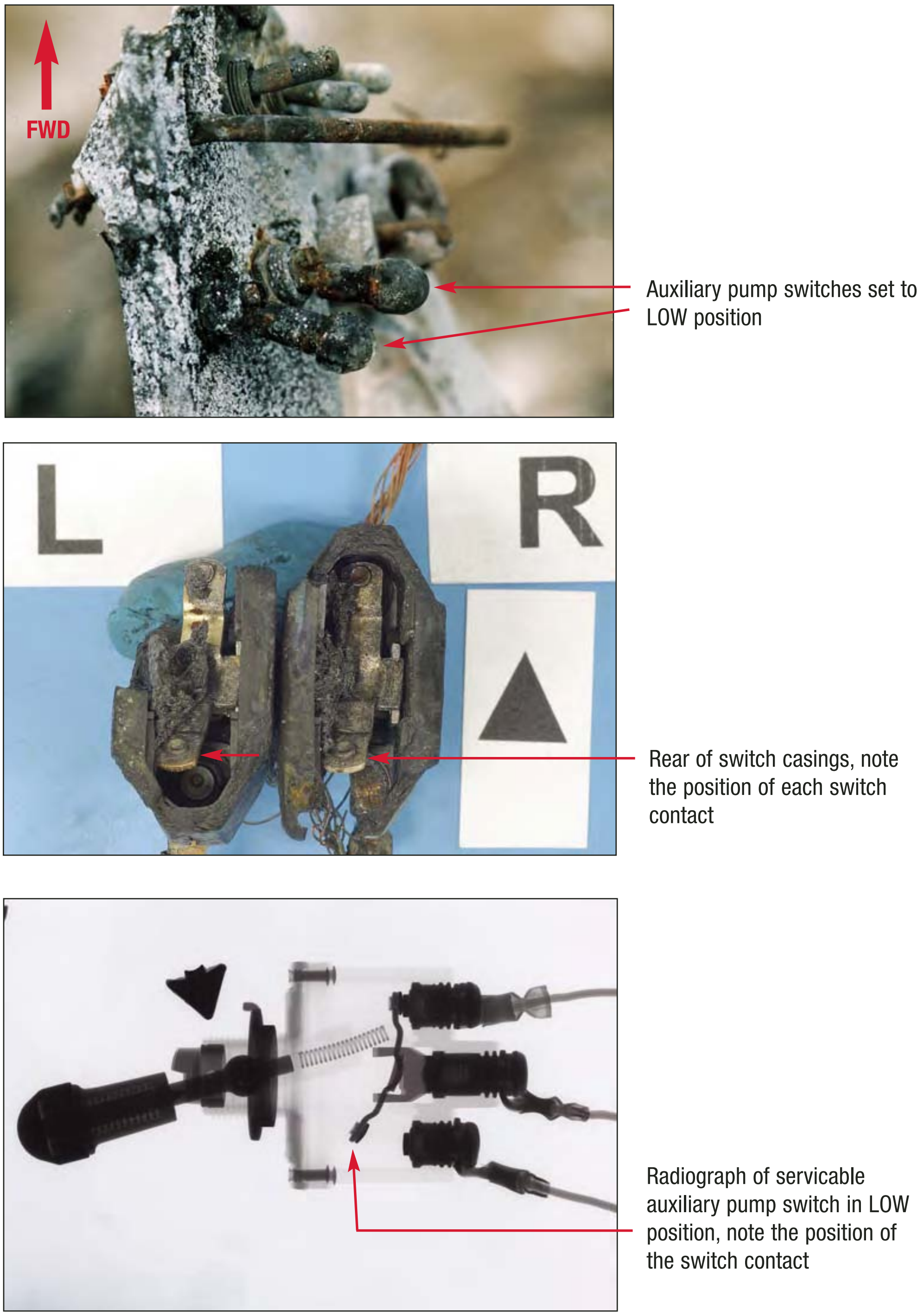


FIGURE 5: Auxiliary pump switch position and comparison with serviceable switch



Auxiliary pump switches set to LOW position

Rear of switch casings, note the position of each switch contact

Radiograph of servicable auxiliary pump switch in LOW position, note the position of the switch contact

Due to post-impact fire damage, the serviceability of the electric auxiliary boost pumps, at the time of the occurrence, could not be determined. Disassembly of the right auxiliary boost pump revealed a missing internal standpipe within the pump body. The pump manufacturer reported that inclusion of the standpipe provided fuel to lubricate and cool the pump bearing. However, the manufacturer also advised that omission of that component would not have had any adverse effect on the operation of the pump.

Post-impact fire damage to the other cockpit switches, controls and instruments precluded further examination.

1.12.2 Right engine and propeller

Disassembly of the right engine did not reveal evidence of internal mechanical malfunction or catastrophic failure. The magneto timing corresponded with the setting recommended by the manufacturer.

Examination of the engine accessory components revealed that the drive coupling to the EDFP had sheared. The spindle shaft of the EDFP could not be rotated by hand. Disassembly of the EDFP revealed galling and material damage to the pump's spindle shaft and sleeve bearing (see section 1.16.1 and Technical Analysis Report 24/04 at Appendix A).

Examination and testing of other engine components and accessories did not identify any additional evidence of mechanical malfunction or significant defects that would have otherwise prevented normal engine operation.

It was not possible to assess the operation of the engine's fuel control unit due to post-impact fire damage.

Examination of the propeller from the right engine confirmed that the blades were in the feathered position at the time of impact. That was consistent with the observed position of the cockpit control lever and the pilot's recollections of having feathered the propeller of the right engine (see Figure 6).

FIGURE 6: Right propeller[19]

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[19] Separation of the pitch-change mechanism of one blade had allowed it to rotate from the feathered position. That damage was assessed as having occurred during the impact sequence.

1.12.3 Left engine and propeller

Disassembly of the left engine and its various accessory components did not reveal any evidence of mechanical malfunction or failure, however a slight discrepancy from the magneto timing recommended by the manufacturer was noted. It was not possible to determine if this discrepancy was the consequence of damage sustained during the impact sequence, or as a consequence of adjustments made during routine maintenance. Notwithstanding, the engine manufacturer reported that such a discrepancy should not significantly have altered the power output of the engine.

It was not possible to assess the operation of the left engine's fuel control unit due to post-impact fire damage.

Examination of the blades of the left propeller revealed several indicators of positive power delivery at impact. The general backwards, out of plane blade bending provided an indication that the blades were in an operational pitch range at impact, with the forward bending displayed by two of the three blade tips, indicating that those blades contacted and entered the ground with a positive angle of attack. Vector analysis revealed that a minimum rotational speed of about 2,000 RPM would have been necessary to induce the forward tip bending observed.[20]

1.13 Medical information

The pilot in command held a CASA Class 1 medical certificate which required that reading correction be available while exercising the privileges of his pilot's licence. The pilot reported that he had reading correction spectacles available to him during the occurrence flight.

He recalled that he was well rested prior to commencing duty at about 0930 on the day of the occurrence. He had been on duty for about 6 hours and awake for about 9 hours at the time of the occurrence.

The investigation found no evidence of any physiological factor that may have impaired the pilot's performance during the occurrence flight.

1.14 Fire

There was no evidence of an in-flight fire. During the impact sequence, the aircraft's fuel tanks were ruptured and a large amount of fuel spilled and ignited. Avgas is a volatile and highly flammable hydrocarbon aviation fuel. Temperatures produced by an aviation fuel-fed ground fire are typically in the range of 870 to 1,100 degrees C. Fire had consumed most of the aircraft's structure before the fire was extinguished by emergency services (see Figure 7).

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[20] Although that determination must be considered an approximation, it provides supporting evidence that the left propeller was rotating towards the upper limit of its speed range at the time of impact.

FIGURE 7: View of aircraft wreckage

1.15 Survival aspects

1.15.1 General

One passenger was fatally injured at the accident site. Post-mortem examination and toxicology testing revealed evidence of smoke inhalation and an elevated level of carbon monoxide (17 per cent). The examination did not reveal any evidence of significant traumatic injury that may have adversely affected his ability to vacate the aircraft.

The remaining occupants vacated the aircraft without assistance, but received serious burns in the process. The pilot also sustained spinal injuries during the accident.

Airport staff, nearby residents and trained medical personnel on duty at the aerodrome provided first aid and medical support prior to the arrival of emergency services and transfer to hospital.

One of the passengers who vacated the aircraft, and who sustained extensive burns to 90 per cent of his body, died 85 days after the occurrence (see footnote 6).

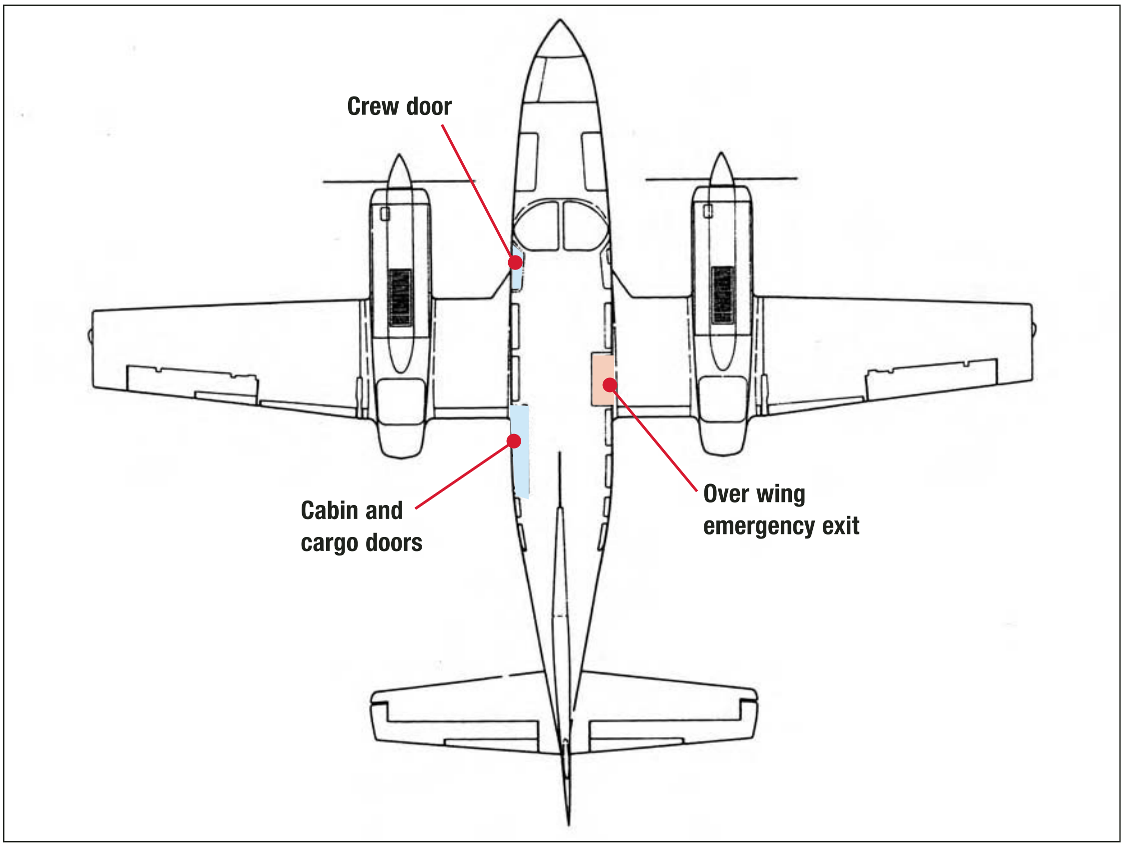
1.15.2 Egress from the aircraft

There were three potential exit paths from the aircraft (see Figure 8). The pilot and three of the passengers reported vacating the aircraft via the door at the rear of the passenger cabin, and recalled that the interior of the aircraft cabin was not significantly affected by fire immediately after the aircraft came to rest. The passenger seated immediately behind the equipment boxes reported that although the upper equipment box moved slightly during the accident, it remained secured to the lower box. The pilot also reported that his egress through the cabin was not impeded. There was no evidence from other passengers that equipment in the cabin had impeded their egress from the aircraft. The passenger who opened the cabin door recalled intense heat with flames in the immediate vicinity of that door. The occupants vacating the aircraft through the rear exit sustained burns to approximately 30 per cent of their bodies. One of the passengers vacating the aircraft through the rear exit also sustained significant burns to his respiratory tract.

The passenger who was fatally injured and did not vacate the aircraft, was reported to have been seated in the rear row and closest to the cabin door. He was reported to have not responded to a rousing command. It was possible that he had been temporarily incapacitated during the accident sequence and was unable to vacate the aircraft immediately after it had come to rest.

It was reported that the passenger who was seated in the copilot's seat, and who died subsequent to the occurrence, vacated the aircraft by kicking out a window on the right side of the aircraft[21] and that '… smoke and fumes …' had prevented egress through the passenger cabin.

FIGURE 8: Location of aircraft exits



1.15.3 Clothing

The CASA website provided information to aircraft passengers regarding safety.

> In the improbable event of an emergency, the clothes you are wearing can play a significant role in your safety. People wear synthetic blend fabrics because they are easy to maintain and do not wrinkle when spending a long time seated. However, they ignite quickly, shrink, melt, and continue burning after the heat source is removed. In the unlikely event that the aircraft is evacuated even pantyhose contribute to injuries, as they melt and cause burns from the friction generated with contact on the slide.
>
> **Clothing**
>
> Wearing clothes made of natural fibres such as cotton, wool, denim and leather offer the best protection during an evacuation or fire. Synthetic fibres (rayon, polycotton and nylon, including

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[21] Those reports indicated that it could have been the cockpit side window, the right over wing emergency exit or another cabin window.

> hosiery, wigs, hairpieces, scarves, ties and underwear) can become very hot and melt causing first, second and even third degree burns.
>
> Avoid leaving large areas of the body uncovered. Steer clear of shorts or skirts because they do not cover extremities. Wear non-restrictive clothing as this allows you greater movement.
>
> By placing a barrier between the fire and the victim, even in the form of covering the skin, some protection from burns will be provided.

The natural fibre clothing worn by the occupants who vacated the aircraft through the cabin door afforded them some protection from burns. The passenger who was reported to have vacated the aircraft through a window on the right side of the aircraft was wearing denim jeans and a shirt made from synthetic fibres, but sustained burns to most of his body, irrespective of any protection provided by his clothing.

1.15.4 Emergency service response

Jandakot ATS notified the WA Police Service communications centre of the accident at 1536:56. The call concluded at 1537:46. Fire and Emergency Services Authority of Western Australia (FESA) records indicated that the FESA communications centre received the accident notification from Western Australia Police at 1539:23, and appliances were dispatched from local fire stations in nearby suburbs, including appliances with an all-terrain capability.

FESA records indicated that the first responding appliances reached the Jandakot Airport emergency gate, about 1,500 m from the accident site, at 1551:52, about 12.5 minutes after being notified by the police. The fire fighting vehicles were not able to track direct to the accident site and had to negotiate runways and bush tracks. The FESA records indicated that the first information from the accident site was received at 1558:28, which stated 'MT is tackling the fire, some persons are out, some persons are missing.' The fire was reported to be under control at 1600:48.

1.15.5 Jandakot Airport rescue and fire fighting service

Jandakot Airport did not have a dedicated aerodrome rescue and fire fighting service (ARFFS) and nor was this required by regulation. ARFFS was previously provided at GAAP aerodromes, such as Jandakot and was industry-funded by a fuel levy. Following industry consultation and review, ARFFS was withdrawn from all GAAP aerodromes in 1991 (see ATSB report 200305496)[22].

The distance between the accident site and the original aerodrome fire station was about 1,500 m. An ARFFS appliance would have taken about 1.5 to 2 minutes to travel that distance, over that terrain.[23] That time would have increased if the aircraft had crashed in a less accessible area of the aerodrome, or outside the aerodrome perimeter.

Since 1992, only 11 per cent of fire related accidents have occurred on, or near major or general aviation aerodromes. The majority of accidents (66%) occurred in areas remote from an aerodrome with just under a quarter of fire related accidents occurring on, or near regional and other aerodromes.

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[22] Following an occurrence at Bankstown Airport in November 2003, the Minister of Transport and Regional Services signed an *Instrument of Direction* for the ATSB to '…investigate the effectiveness of the fire fighting arrangements for Bankstown Airport, as they affected transport safety…'. Bankstown Airport is a General Aviation Aerodrome Procedures (GAAP) aerodrome which had similar provisions for aerodrome rescue and fire fighting services (ARFFS) as Jandakot Airport at the time of the occurrence involving ANV.

[23] Using information provided by ARFFS to estimate the approximate response time for an on-aerodrome ARFFS appliance, assuming that the appliance crew were already in the vehicle and ready to respond.

1.15.6 National regulations

Safety regulation of civil air operations in Australia and the operation of Australian aircraft overseas is the primary function of CASA.

At the start of the 1990s a decision was made to remove ARFFS at some aerodromes. Services were removed from all GAAP aerodromes[24] following consultation with the aviation industry and the aerodrome operators. Rescue and fire fighting services were withdrawn from Jandakot in 1991.

The CASA safety regulations in relation to ARFFS are contained in Civil Aviation Safety Regulation (CASR) Part 139 Subpart H – Aerodrome rescue and fire fighting service. CASR Subpart 139 H was adopted on 26 June 2002, for commencement on 1 May 2003, following industry consultation conducted since March 2000.[25]

It was intended that Part 139 Subpart H would place an obligation on aerodrome operators to provide an ARFFS, for aerodromes from, or to, which an international passenger air service operated, and any domestic aerodrome through which more than 350,000 passengers passed on air transport flights during the previous financial year. The publication stipulated an operational directive to achieve response times[26] requiring, under optimum conditions, the ARFFS to reach the end of any runway within three minutes of notification. The operational objective of the ARFFS was to achieve a response time not exceeding two minutes to the end of each runway and not exceeding three minutes to any part of the manoeuvring area[27].

This standard was aimed at minimising the risk for the greatest number of passengers. However, subsequent actions following the tabling of a disallowance motion in Parliament removed both the obligation for anyone to provide an ARFFS or requiring the provision of an ARFFS. The Department of Transport and Regional Services (DOTARS) has taken action to re-insert establishment criteria in the CASRs.

Of Australia's 600 aerodromes, Airservices Australia provides ARFFS at eight capital city and nine regional aerodromes[28] in line with the Government's policy of providing ARFFS at aerodromes exceeding 350,000 passengers in the previous financial year, or that have international air services.[29] There is nothing precluding an airport operator of an airport that falls outside the criteria, should they choose to, from providing a non-ARFF service at their airports, or from requesting a certified supplier to provide an ARFFS to an appropriate standard.

The Manual of Standards Part 139 H – *Standards Applicable to the provision of Aerodrome Rescue and Fire Fighting Services*, states that all operational ARFFS staff must comply with CASA standards that require a current qualification and certificate of competency commensurate with the functional role at a specific location. Those competencies include casualty assistance, emergency care, emergency life support techniques and how to operate life-support equipment.[30]

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[24] Includes Bankstown NSW, Parafield SA, Jandakot WA, Camden NSW, Moorabbin Vic., and Archerfield Qld.

[25] Information about the consultation process is available from the CASA website www.casa.gov.au/avreg/newrules/casr/139h.htm

[26] The time between the initial call to the ARFFS and the time when the first responding vehicle was in position, and if required, producing foam at a rate of at least 50% of the specified discharge rate.

[27] That part of the aerodrome used for the takeoff, landing and taxiing of aircraft, excluding aprons.

[28] Airservices Australia data available at www.airservicesaustralia.com/services/ps7/contracts2.asp

[29] House of Representatives Standing Committee on Transport and Regional Services report, *Regional Aviation and Island Transport Services: Making Ends Meet*. The report is available at www.aph.gov.au/house/committee/trs/aviation/report/contents.html

[30] Certificate II and III level of Australian Fire Competency.

The Department of Transport and Regional Services collects aviation statistics on passenger movements at Australian aerodromes. However, the data gathered is limited to passengers from international, domestic and regional airline scheduled air transport flights at 94 aerodromes. That data did not include passengers carried on charter or other non-scheduled air transport flights, and it did not include those aerodromes that received less than 7,000 revenue passenger movements in 2002–03. Jandakot Airport does not have scheduled air transport passenger flights and is not an international airport.[31] The passenger data from Jandakot and other GAAP aerodromes is excluded from the DOTARS annual statistical publication.

The *En Route Supplement Australia* (ERSA) details the ARFFS for each aerodrome listed. The Jandakot ERSA entry has no ARFFS detailed.

On Monday 1 December 2003, the House of Representatives Standing Committee on Transport and Regional Services tabled its report *Regional Aviation and Island Transport Services: Making Ends Meet*. The report followed an inquiry into commercial regional aviation services in Australia and transport links to major populated islands.

The inquiry looked at the cost of aviation (aerodrome) rescue and fire fighting services, and the conditions under which these services are now provided following industry concerns. It found that there was some disagreement in the evidence about the justification for fire fighting and rescue services being provided at aerodromes. The cost of providing the service is determined by the equipment needed to meet the standards for delivering water and foam within an aerodrome during a call-out. At some aerodromes around the world, and in Australia, it has been found to be more cost effective for aerodrome fire fighting and rescue services to be provided by the fire service serving the local community. At Jandakot, where there are no scheduled passenger services, the aerodrome fire fighting and rescue service is provided by the FESA.

The inquiry found that there were two issues to be considered:

- the provision of rescue and fire fighting services to aerodromes with limited numbers of passenger landings
- whether these services are provided by Airservices Australia or by local fire services.

The committee report contained the following recommendations:

- The Department of Transport and Regional Services and Airservices Australia introduce a universal service charge for aerodrome rescue and fire fighting services at regional aerodromes to reduce the wide disparity in the charges for those services and to reduce the overall impact of the charges on regional aviation costs
- The Department of Transport and Regional Services and Airservices Australia form a working group with key stakeholders (such as the relevant local government associations, town planning and standards bodies) to advise on the strategic and optimal co-location of fire fighting services
- Airservices Australia provide the initial aerodrome rescue and fire fighting equipment and crew training, at no cost, to communities where fire fighting services become co-located.

The Government is currently considering its response to this comprehensive report.

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[31] Data on the number of passengers using non-scheduled services such as charter flights is not available, as indicated by the preceding discussion.

1.16 Tests and research

1.16.1 Examination of engine-driven fuel pumps

Metallurgical examination (see Technical Analysis Report 24/04 at Appendix A) confirmed that the drive coupling to the right EDFP was free of manufacturing defects or material anomalies and had failed in torsional overload. Detailed examination of the spindle shaft and sleeve bearing from the right EDFP revealed localised areas of abnormal adhesive wear (galling). Analysis of that galling indicated that the damage was sustained in service, and had resulted in a partial seizure between the spindle shaft and sleeve bearing. That resulted in the torsional overload failure of the drive shaft and the consequent loss of drive to the pump.

A comparative analysis between the left and right sleeve bearings revealed a significant difference in their material characteristics. The bearing sleeve from the right EDFP was manufactured from an aluminium bronze alloy, whereas the sleeve bearing from the left EDFP was manufactured from a high-leaded bronze. Analysis of those materials revealed that, although aluminium bronze produced a hard, high strength and corrosion resistant bearing that exhibited a reduced rate of wear, it also demonstrated reduced galling resistance and hard particle embeddability[32] as compared with the characteristics of high-leaded bronze. That made aluminium bronze an inferior material choice for use in an EDFP when compared with the superior anti-galling characteristics of high-leaded bronze.

The sleeve bearing of the right EDFP had been remanufactured and replaced during a local overhaul of the pump, in accordance with an engineering order, which specified the use of aluminium bronze alloy for the manufacture of the replacement sleeve bearing. The process of producing the engineering order did not identify that the original equipment manufacturer (OEM) specification was for the use of high leaded bronze in bearing manufacture. The right EDFP had operated for 1,353.3 hours since remanufacture of the sleeve bearing.

1.16.2 Analysis of ATS radar data

ATS radar data[33] was obtained from the Secondary Surveillance Radar located at Kalamunda, approximately 12 NM north-east of Jandakot Airport. Technical analysis aligned that data with known ground features and provided a high correlation with subsequent witness reports of the aircraft’s flight path. Analysis of the aircraft’s airspeed incorporated an adjustment for the wind velocity recorded by the aerodrome’s AWS.[34]

The first radar return from the aircraft’s transponder was recorded at 1534:22, before ANV had been cleared to take off, and when it was at the runway 24R displaced threshold (see Figure 1). Radar returns from the transponder were intermittent due to the aircraft’s low altitude. The second radar return from ANV was recorded at 1535:10, during the take-off roll. The third radar return was recorded at 1535:21, when ANV had passed upwind of the intersection with taxiway Golf. The fourth radar return was recorded at 1535:28, as ANV was close to the departure end of the runway and slightly right of the runway centreline. At that point, recorded radar data revealed an incremental increase in altitude from the previous positions. The radar point-to-

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[32] Embeddability is the ability of the bearing lining material to absorb, or embed within itself, any of the larger of the small dirt particles present in a lubrication system. *Machinery's Handbook*, 27th Edition, Industrial Press, page 2260.

[33] ATS radar data points were recorded every 3.7 seconds, and included information about the altitude of the aircraft, which was reported by the aircraft transponder to the nearest 100 ft.

[34] That data was recorded minute by minute and included the average wind direction and speed during the preceding minute, together with the maximum recorded wind gust during that period.

point groundspeed was corrected for AWS recorded wind speed, compressibility and density errors, which indicated an airspeed of 103 KCAS[35]. Due to the limitations of the radar data recorded during the initial take-off roll, it was not possible to calculate the speed of the aircraft until after the power loss on the right engine had occurred.

To improve the quality of subsequent airspeed calculations, the recorded radar data was smoothed using a technique of 2, 3 or 4-point moving averages.[36] The investigation considered that the smoothed KCAS airspeed values were representative of the aircraft's actual airspeed +/- 5 kts. ANV commenced a left turn shortly after 1535:39 and the recorded radar track stabilised on a track of about 130 degrees true. During the turn, the radar-derived airspeed reduced from 105 to 85 KCAS. After completing the turn, the radar-derived airspeed gradually increased to 103 KCAS. Recorded radar data was consistent with the aircraft then turning onto a left base for runway 12. During that turn, the radar-derived airspeed reduced progressively to 87 KCAS. The last radar return was recorded at 1536:42.

The altitude reported by the aircraft's transponder remained one increment (100 ft) above the runway indication for the duration of the flight.

1.17 Organisational information

1.17.1 Aircraft operator

The aircraft operator held a CASA Air Operator's Certificate (AOC) that authorised aerial work operations.[37] CAR 206 defined aerial work purposes and included operations such as aerial surveying, aerial spotting and substantially similar purposes.

The aircraft operator published an operations manual which detailed operating procedures and administrative requirements. The manual required pilots to operate aircraft in accordance with the manufacturer's operating procedures and checklists contained in the AFM, unless otherwise documented in the manual. Part B of the operations manual included information about emergency procedures.

Part B1.3.3 of the operations manual required that, in the event of an engine failure in a multi-engine aircraft immediately after takeoff, pilots were to '…follow the loss of engine self brief take-off shut down procedures…'. During interview the chief pilot reported that the operations manual did not detail the required contents of that briefing, nor did it contain information about the factors to be considered for such a briefing. He said that he did not want a generic briefing recited, but rather, wanted pilots to think about each departure and base their briefings on the relevant factors. He also reported that, during proficiency checks with the pilot of ANV, he had received briefings in accordance with his expectations. The chief pilot stated that take-off decision speed was to be based on either the aircraft achieving the best one-engine inoperative rate of climb speed or alternatively, from a long runway, the point at which a landing was no longer possible. The pilot of ANV stated that he used 95 KIAS[38] as the rotation speed and a decision speed of 109 KIAS.

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[35] KCAS is calibrated airspeed in knots. The AFM indicated that the calibrated airspeed was within 1 knot of the indicated airspeed (KIAS) in the take-off configuration.

[36] Radar measures position in range and azimuth. Limitations in the measurement of range and azimuth can result in unrealistic oscillations and the technique of data smoothing attenuates those oscillations. That process gives average values, but can also eliminate realistic peaks in the recorded data.

[37] Subsequent to the occurrence, CASA advised the ATSB that in accordance with CASA ruling 3/2044, dated 13 September 2004, the occurrence flight was classified as an aerial work purpose.

[38] Knots indicated airspeed.

The operations manual stated that engine failures were not to be simulated between take-off safety speed minus 5 kts, and take-off safety speed plus 10 kts, or once airborne, until positive rate-of-climb is indicated on the vertical speed indicator. The chief pilot advised that he did not conduct simulated engine failures below a height of 300 ft above ground level. The operator did not provide training for simulated emergencies using a synthetic training device, and nor was it required to do so by regulation.[39]

1.17.2 Aircraft hirer

The aircraft had been hired by a company providing specialised contracting support to the Royal Australian Navy (RAN). The occurrence flight was the first of a series scheduled for that week and involved maritime operations, approximately 40 NM west of Jandakot. Five employees of the RAN contractor were tasked to operate their on-board electronic and communications equipment during the flight and perform other functions. The contractor reported that each of those passengers were essential for the conduct of the operation.

1.18 Additional information

1.18.1 Regulatory requirements for one-engine inoperative climb performance

CAO 20.7.4 was applicable to aerial work and charter operations for multi-engine aircraft (operating under the instrument flight rules) and required aircraft to be capable of a 1 per cent en route climb gradient (at all heights up to 5,000 ft in the standard atmosphere). At the manufacturer's published one-engine inoperative best rate of climb speed of 108 KIAS, that requirement represented a one-engine inoperative climb rate (nil wind) of 108 ft/min.

1.18.2 Aircraft stall speed

At a weight of 3,773 kg, the wings-level, power-off stall speed with wing flaps UP was 82 KIAS. With the wing flaps in the T.O. & APPR. position, the wings-level, power-off stall speed was 73 KIAS. The AFM stated that buffet[40] could occur at airspeeds as high as 88 KIAS at maximum take-off weight (MTOW) with the wing flaps in the UP position. The stall speed increased during turning flight and was 85 KIAS at 20 degrees angle of bank (wing flaps UP) and 88 KIAS at 30 degrees angle of bank.

1.18.3 One-engine inoperative speeds

3,810 kg MTOW, standard day at sea level	*Flap & gear UP*	*Flap T.O. & APPR. and gear UP*
Air minimum control speed (V_{mca})	N/A	78 KIAS
Intentional one-engine inoperative speed (V_{sse})	102 KIAS	91 KIAS
Best one-engine inoperative angle of climb speed (V_{xse})	105 KIAS	98 KIAS
Best one-engine inoperative rate of climb speed (V_{yse})	109 KIAS	102 KIAS

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[39] The use of synthetic training devices for aircraft below 5,700 kg is discussed in ATSB Investigation Report BO/200105618.

[40] Buffet refers to the irregular oscillation of an aircraft's structure, caused by turbulent wake.

During certification testing, the aircraft manufacturer was required to determine the critical[41] engine. That testing confirmed that the failure of the left engine resulted in the greatest performance penalty, and under the conditions of the flight test, resulted in approximately a 50 ft/minute lower rate of climb than obtained with a failure of the right engine.

The air minimum control speed (V_{mca}), determined by the aircraft manufacturer during certification testing, was based on the critical engine inoperative with the propeller windmilling, take-off power on the operating engine, most rearward centre of gravity at MTOW, flap set to T.O. & APPR., landing gear retracted, maximum of 5 degrees of bank towards the operating engine and ½ ball displacement on the turn and bank indicator. The air minimum control speed was the minimum speed under those criteria at which directional control of the aircraft could be maintained.

The speed to achieve the best one-engine inoperative rate of climb was dependent on the aircraft operating weight and altitude. For the conditions at the time of the occurrence, and at the aircraft's estimated operating weight, the airspeed to achieve the best one-engine inoperative rate of climb was 108 KIAS.

1.18.4 Take-off performance data

Take-off performance charts issued by the manufacturer indicated that the aircraft could take off with the wing flaps retracted or at the T.O. & APPR. position. Those charts indicated (see Appendix B) that under the prevailing conditions, the required takeoff distance, to reach an altitude of 50 ft at the take-off safety speed (V_{TOSS})[42] from a standing start was 680 m with wing flaps T.O. & APPR., and 800 m with wing flaps retracted. That increased distance was as a consequence of the higher V_{TOSS} required with the wing flaps retracted. In determining the take-off distance required, CAO 20.7.4 required that the distance be increased by a factor of 1.25.

The data published by the manufacturer (see Appendix B) also stated the following distances for the prevailing conditions:

Distances based on level, dry, hard runway surface at 3,773 kg	***Flaps UP (V_{TOSS} 101 KIAS)***	***Flaps T.O. & APPR. (V_{TOSS} 90 KIAS)***
Accelerate-stop distance[43] (full power prior to brakes release, engine failure at V_{TOSS} and stop using maximum braking)	1,222 m	981 m
Accelerate-go distance (full power prior to brakes release, engine failure at V_{TOSS} and go, climb to 50 ft)	1,320 m	1,391 m

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[41] Failure of the critical engine produced the greatest yawing moment, required larger inputs of rudder/aileron and consequently, the failure of that engine resulted in the greatest performance penalty.

[42] Take-off safety speed may be defined as the speed selected to ensure that adequate aerodynamic control will exist under all conditions, including sudden, complete engine failure, during the climb after takeoff.

[43] Accelerate-stop distance may be defined as the distance required to accelerate an aircraft to a specified speed and, assuming failure of an engine at the instant that speed is attained, to bring the aircraft to a stop. There was no requirement in CAO 20.7.4 for accelerate-stop distance to be considered for operation of the occurrence aircraft.

For the conditions prevailing on the afternoon of the occurrence, the AFM recommended a takeoff with wing flaps retracted if obstacle clearance was a consideration for continuing the takeoff attempt following an engine failure. That recommendation was due to the improved climb performance with wing flaps retracted.

1.18.5 One-engine inoperative rate of climb

The AFM provided information about the predicted one-engine inoperative performance of the aircraft following the failure of the critical engine (see Appendix B). The data indicated that, under the prevailing conditions, the aircraft should achieve a climb rate of about 220 ft/min[44] with the landing gear retracted, wing flaps retracted, the propeller of the inoperative engine feathered, 5 degrees of bank towards the operating engine and approximately ½ ball displacement on the turn and bank indicator. The data also indicated the approximate performance penalty with landing gear extended (300 ft/min reduction in rate of climb), flaps positioned to T.O. & APPR. (100 ft/min reduction in rate of climb) and windmilling propeller (350 ft/min reduction in rate of climb).

A number of factors[45] could affect the aircraft's one-engine inoperative performance, including any variation from the airspeed to achieve the one-engine inoperative best rate of climb, control inputs made by the pilot to manage the situation and the effect of manoeuvring the aircraft. One-engine inoperative climb performance would have significantly reduced during turning manoeuvres. The investigation calculated that the predicted climb performance would reduce by at least 25 per cent during a 10 degree angle of bank turn, 50 per cent during a 20 degree angle of bank turn and more than 90 per cent during a 30 degree angle of bank turn.

1.18.6 One-engine inoperative angle of climb

The aircraft manufacturer did not provide information in the AFM about the predicted one-engine inoperative angle of climb performance, nor was there a requirement to do so.

The investigation calculated the climb gradient and approximate required rate of climb that would have been required, under the prevailing meteorological conditions, to clear the powerline tower (see section 1.10.4). Calculations for a climb performed at the manufacturer's published speed for best one-engine inoperative angle of climb[46] of 105 KIAS indicated:

- a required climb gradient of 1.93 per cent from the upwind threshold, at a climb rate of about 186 ft/min
- a required climb gradient of 1.65 per cent from taxiway Golf, at a climb rate of about 159 ft/min.

From a height of 50 ft overhead the upwind threshold, the required climb gradient was 1.3 per cent at a climb rate of about 125 ft/min. From 50 ft overhead taxiway Golf, the required climb gradient was 1.11 per cent at a climb rate of about 106 ft/min.

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[44] That equated to a climb gradient of about 2.23 per cent under the prevailing conditions.

[45] Those include aircraft configuration, aircraft gross weight and density altitude.

[46] Best one-engine inoperative angle of climb is relevant to maximise the aircraft's angle of climb as measured over the ground.

1.18.7 Recommended procedures – engine failure after takeoff

The AFM contained procedures and checklists recommended by the aircraft manufacturer for the safe operation of the aircraft, including emergency procedures and checklists (see Appendix B). The checklist covering engine inoperative procedures indicated that the takeoff should be discontinued following an engine failure after takeoff with airspeed below 91 KIAS or landing gear down.

The AFM identified an 'area of decision' for making a 'go no-go decision', which was the period during which, on experiencing an engine failure, the pilot would need to decide to either continue or discontinue the take-off attempt. That region was defined as the point from which the aircraft became airborne to the point at which it reached an altitude higher than surrounding obstructions. The AFM indicated that the aircraft accelerated through this area of decision in '…just a few seconds…'. In deciding to continue or discontinue the takeoff, the AFM recommended that the pilot consider the field length, obstruction height, field elevation, air temperature, headwind and take-off weight. It also noted that an engine failure in that area required an immediate decision. The AFM also indicated that discontinuing a takeoff upon engine failure was advisable under most circumstances.

The AFM checklist for an engine failure after takeoff, airspeed above 91 KIAS with the landing gear up or in transit included closing the throttle of the inoperative engine, positioning the mixture control lever of the inoperative engine to idle cut-off and then feathering the propeller, in that order (see Appendix B).

The AFM also indicated that when landing on smooth ground with wheels retracted, the aircraft would slide straight ahead about 250 m with very little damage.

1.18.8 Pre-flight planning and briefing

The pilot reported that he did not perform any calculations of the minimum climb gradients required for obstacle clearance and that he did not assess the aircraft's engine-out climb performance as a normal part of his pre-flight planning. He reported that he anticipated a very low climb rate following any engine failure and noted that the data published by the aircraft manufacturer was for a new aircraft and may be different from the actual performance achieved for older aircraft.

The pilot stated that he had conducted a pre-takeoff safety self-briefing in accordance with the operator's practice. However, that briefing did not include contingencies, in the event of an engine failure, for off-aerodrome emergency landing areas, or minimum altitudes to achieve prior to attempting a return for a landing.

The operator's operations manual did not provide guidance to pilots for such contingencies. Additionally, there was no formal guidance provided by CASA to pilots about managing engine failures or power losses during critical stages of the takeoff.

1.18.9 Previous similar occurrences

Following an accident in 1999, the United Kingdom's Aircraft Accident Investigation Branch (AAIB) performed flight tests in a C404 aircraft. The AAIB investigation report found that the:

> …aircraft's one-engine inoperative climb performance before and after feathering the propeller was close to the figures obtained from the appropriate graph in the Cessna Information Manual.

The report also noted that:

> …once the airspeed had decayed below the optimum for one-engine inoperative performance, the aircraft's one engine inoperative climb performance was seriously affected.

In addition, on 27 November 2001, a Beech C90 King Air crashed after takeoff following the failure of the critical engine during the take-off roll (see ATSB Investigation Report BO/200105618). That occurrence displayed similar characteristics to ANV. As a result of that occurrence, a number of safety recommendations were made. Those recommendations are further discussed at Section 4.

1.19 New investigation techniques

Not relevant to this investigation.

2 ANALYSIS

2.1 Introduction

ANV impacted trees and terrain while the pilot was attempting to return the aircraft to the aerodrome for an emergency landing, following a loss of power to the right engine during the takeoff.

Damage sustained by the aircraft during the impact sequence caused a significant quantity of fuel to spill from the aircraft's fuel tanks. The ignition of this fuel resulted in an intense post impact fire. The aircraft was under the positive control of the pilot prior to the initial impact.

The operating weight of the aircraft was estimated to be below the maximum permitted takeoff weight and the centre of gravity was calculated to be within the published limits. The wing flaps were set at the T.O. & APPR. position for the takeoff.

2.2 Failure of the right engine driven fuel pump

A partial seizure of the right engine-driven fuel pump's (EDFP) spindle shaft and sleeve bearing, resulted in high torsional loads. As a result of those high loads, the drive coupling to the EDFP sheared. Consequently, the EDFP was unable to provide sufficient fuel flow to sustain engine operation at take-off power.

Metallurgical examination of the sleeve bearing and spindle shaft from the EDFP revealed localised galling damage - an abnormal wear mechanism that can lead to high friction and seizure. The sleeve bearing had been remanufactured under the specifications of an engineering order during the last component overhaul. Although the manufacture of the replacement component correctly complied with the requirements of the engineering order, the specified material did not possess the galling resistance properties required for use with a high-speed fuel pump.

The decrease in fuel pressure associated with the failure of the EDFP would have been indicated to the pilot on the cockpit fuel flow gauges and associated with a loss of engine power.

2.3 Right auxiliary fuel pump

The switching system for the aircraft's auxiliary fuel pumps complied with the conditions of an earlier service bulletin issued by the aircraft manufacturer. The service bulletin removed the original design feature that provided automatic switching of the auxiliary fuel pump to high following a decrease in fuel pressure.

Normal operating procedures for the C404 required the auxiliary fuel pumps to be used in the LOW position for each takeoff. Fragments of the auxiliary pump switches recovered from the wreckage were set to the LOW position at the time of the post-impact fire. However, the low-pressure fuel supplied by the auxiliary fuel pump was insufficient to sustain engine operation at the take-off power setting.

In the event of an EDFP failure, selection of the auxiliary pump switch to the HIGH position would have increased the fuel pressure to the engine, and therefore assured continued operation of the engine at higher power settings. The AFM supplement indicated that HIGH output from the auxiliary fuel pump may not be sufficient for normal engine operation at high manifold pressure and high RPM. In that case, the supplement recommended reducing manifold pressure to a setting compatible with the indicated fuel flow.

See also Section 2.6, for procedures recommended by the aircraft manufacturer.

2.4 Loss of engine power

Recorded ATS radar data indicated that the aircraft deviated right of the runway centreline prior to the upwind threshold. Limitations associated with the radar data during the take-off roll precluded a reliable estimation of the aircraft's airspeed at the time of the loss of engine power. The radar data was consistent with the controllers' recollection of hearing a change in engine note when the aircraft had just passed taxiway Golf. The investigation concluded that the loss of engine power had occurred soon after the aircraft became airborne and during the first 50 ft of the climb. The radar data and witness reports indicated that the loss of power had probably occurred about 820 m from the commencement of the take-off roll.

2.5 Aircraft manufacturer's emergency procedures

The aircraft manufacturer's emergency procedures stated that an aircraft should be landed straight ahead, in the event of an engine failure with the landing gear extended. At the time of the loss of power, insufficient runway remained for a normal landing. If the pilot had discontinued the take-off attempt, a runway overrun was inevitable. However, the cleared terrain immediately upwind of the runway extended at least 275 m beyond the departure end of the runway.

Above an airspeed of 91 KIAS and with the landing gear retracted or in transit, the procedure recommended by the manufacturer and contained in the AFM, emphasised completion of immediate action items to maximise aircraft performance, rather than conducting troubleshooting of aircraft systems. The checklist did not include any requirement to check the fuel flow to the inoperative engine, or make changes to the switch position for the auxiliary fuel pump. The checklist included closing the throttle of the inoperative engine, positioning the mixture control to idle cut-off and feathering the propeller, in that order. That was consistent with the limited amount of time available for the pilot to react to the engine malfunction and to maximise the performance of the aircraft.

2.6 Pre-flight performance planning

The pilot had operated from Jandakot Airport for a number of years and was familiar with the aerodrome environment. For a takeoff from runway 24R, he did not assess that there were obstacles in his intended flight path that would have affected the aircraft take-off configuration. Accordingly, he did not perform any calculations to assess the climb rate required to ensure obstacle clearance, in the event of an engine failure.

The pilot reported that, during the accident flight, he initiated the turn from the runway heading because he was concerned about flight over residential areas and the high-tension powerlines ahead. Neither the pilot nor the aircraft operator's chief pilot had considered the powerlines upwind from runway 24R as obstructions for the purpose of their pre-takeoff safety briefings.

Notwithstanding, pre-flight performance planning, using the aircraft manufacturer's published performance data could have assisted the pilot identify factors that may have affected the safe conduct of the flight. That process could have clarified contingency planning for events such as an engine failure, or loss of power during a critical phase of flight, particularly when damage to the aircraft was a possible consequence of a runway overrun or a wheels-up landing. Contingency planning could also be included in a pilot's pre-takeoff safety self-brief in order to optimise the management of an aircraft emergency.

2.7 Take-off configuration

Runway 24R at Jandakot was the longest runway. The pilot performed the takeoff using the operator's standard configuration (flap T.O. & APPR. position) and the takeoff was commenced from the displaced landing threshold for runway 24R. That take-off position reduced the available take-off run by 145 m. Use of the full length of the runway would have increased the stopping distance available, in the event that the takeoff was discontinued, or increased the distance available to climb above any obstacles in the take-off flight path in the event that the takeoff was continued.

Information contained in the AFM indicated that a takeoff without flap would significantly improve the aircraft's one-engine inoperative climb performance.

The AFM also recommended that if the predicted one-engine inoperative performance exceeded the runway length available, or if obstacle clearance requirements could not be achieved:

- that the takeoff be performed on a more favourable runway, or
- that the aircraft weight be reduced, or
- that the takeoff be delayed until more favourable atmospheric conditions existed.

2.8 Standard operating procedures – engine failure during takeoff

The operator's stated procedure required that pilots were not to initiate retraction of the landing gear before the aircraft had reached the airspeed to achieve the flap-UP, best one-engine inoperative rate of climb (V_{yse}). That speed varied according to the operating weight of the aircraft and was 108 KIAS for the weight calculated by the investigation team for that takeoff. The operator required pilots to use V_{yse} as the take-off decision speed. The operator's procedure required that the takeoff be discontinued in the event of an engine failure below that speed. The pilot reported that he used 109 KIAS as the take-off decision speed and that the aircraft had achieved this speed prior to the point of engine failure. There were insufficient ATS radar data points recorded during the take-off roll to reliably verify the aircraft's speed at the time of the loss of power.

A pilot following the operator's standard procedure would have initiated retraction of the landing gear once airborne and after the aircraft had reached the decision speed. The pilot's recollection of reaching to retract the landing gear when initially detecting the loss of power could suggest that the aircraft was close to the decision speed when that event occurred.

2.9 One-engine inoperative climb performance

The AFM indicated that the aircraft should be capable of a positive rate of climb at the best one-engine inoperative rate of climb speed, and should be capable of achieving a climb rate of about 220 ft/min, based on a failure of the critical (left) engine. Accordingly, following failure of the less critical (right) engine, the aircraft should have been capable of a climb rate greater than 220 ft/min. That climb performance would be reduced with flap in the T.O. & APPR. position (approximately 100 ft/min reduction), landing gear extended (approximately 300 ft/minute reduction) and a windmilling propeller (approximately 350 ft/minute reduction).

A number of factors were identified that could have affected the aircraft's actual one-engine inoperative performance, including:

- differences between ANV and the aircraft used during the manufacturer's test flying program
- the actual airspeed attained by ANV during the occurrence flight
- the degree of coordination achieved by the pilot between the rudder, ailerons and elevator inputs to optimise the aircraft's one-engine inoperative performance.

Analysis of the recorded ATS radar data, allowing for the AWS recorded headwind component, indicated that the aircraft's airspeed upwind of runway 24, and prior to turning, was between 100 and 110 kts. The airspeed to achieve the maximum one-engine inoperative angle of climb was 105 KIAS, and the best one-engine inoperative rate of climb (flap UP) was 108 KIAS.

The aircraft's one-engine inoperative performance would be significantly reduced during turning manoeuvres.

The pilot reported that his takeoff safety briefing did not include any assessment of aircraft climb performance following any engine failure nor did it identify any minimum altitude to achieve prior to attempting a return to land. His briefing did not include the actions required in the event that the aircraft's one-engine inoperative performance was insufficient to achieve obstacle clearance, such as using the power from the operating engine to reach an emergency landing area along the aircraft's flight path.

2.10 Flight path after takeoff

Recorded ATS radar data indicated that the aircraft commenced a left turn about 20 seconds after becoming airborne. During that time the pilot had been required to respond to the initial loss of power, retract the landing gear and wing flaps and initiate feathering the propeller of the inoperative engine. As the wing flaps retracted there would have been a transient reduction in lift, that could have appeared to the pilot as a reduction in aircraft climb performance and would have made if difficult for the pilot to accurately assess the aircraft's one-engine inoperative climb performance and its ability to climb clear of obstacles.

Based on the AWS recorded wind, the radar data indicated that the aircraft's airspeed was between 100 and 110 kts prior to the initial turn from runway heading. During the turn the airspeed decreased to between 80 and 90 kts, after which, the airspeed stabilised before increasing again to between 98 and 108 kts. The radar data indicated that while the airspeed was increasing, the aircraft was not executing significant turning manoeuvres and remained at a height of about 100 ft above aerodrome elevation.

Analysis of the radar data indicated that the airspeed reduced significantly during turning manoeuvres and had reduced below the speed at which the AFM states that stall buffet can occur. The actual degradation of aircraft performance during a turn would depend upon the angle of bank used and the coordination of the flight controls to maintain optimum performance. The radar data indicated that the airspeed had reduced below the manufacturer's published speed for intentional one-engine inoperative flight.

Analysis of radar data indicated that the aircraft was flying below the one-engine inoperative best rate of climb speed for most of the flight. At the point of the last recorded radar return, allowing for the AWS recorded wind, the aircraft's airspeed was between 15 and 25 kts below the one-engine inoperative best rate of climb speed and the aircraft's performance had degraded such that it was not possible to maintain level flight.

Following the loss of power, the pilot had attempted to manoeuvre the aircraft for a landing on runway 30. Approaching the point of the last recorded radar return, the aircraft was not in a position to turn onto final approach for runway 30 without use of moderate to excessive angle of bank. It was likely that such manoeuvring would have reduced the aircraft's performance below that required to maintain positive control.

2.11 Training

The operator performed regular training and checking flights with its pilots in accordance with a CAR 217 approval. The operator stated that, for safety purposes, simulated engine failures were not conducted at airspeeds less than take-off decision speed plus 10 kts, or below 300 ft above ground level. The operator did not provide training for simulated emergencies using a synthetic training device, and nor was it required to do so by regulation. The investigation concluded that the pilot experienced an emergency situation, at a critical phase of flight, for which training in the aircraft had not been provided.

2.12 Fire

There was no evidence of an in-flight fire. During the impact sequence, a large amount of fuel spilled due to impact damage to the aircraft fuel tanks. That fuel ignited prior to impact with the ground but after initial contact with the trees. The investigation identified a number of possible sources of ignition for the spilled fuel including (but not limited to):

- capacitors from the power pack of the wing strobe light
- arcing from broken electrical wires in the sheared wing
- hot engine components.

The intensity of the fire and radiant heat energy from the burning fuel in the vicinity of exit paths from the aircraft resulted in burns to the aircraft occupants.

The intensity of the post impact fire and the proximity of the aircraft cabin to the burning fuel indicated conditions in the aircraft cabin would have quickly deteriorated after the aircraft came to rest. It was not possible for the investigation to accurately assess the length of time following the accident that conditions within the passenger cabin would have remained survivable, nor otherwise assess the effectiveness of an on-aerodrome ARFFS.

While some enhancement in response times might be possible with the provision of a location specific ARFFS there remains the problem with the randomness of accident locations as indicated by the data on previous fire related accidents (see 1.15.5).

3 CONCLUSIONS

3.1 Significant factors

1. The material specification contained in the engineering order for replacing the pump bushing of the engine driven fuel pump (EDFP) fitted to the right engine was not appropriate.
2. High torsional loads between the EDFP's spindle shaft and the sleeve bearing sheared the pump's drive shaft during a critical phase of flight.
3. The reduction in fuel pressure was insufficient to sustain operation of the engine at the take-off power setting.
4. The loss of engine power occurred close to the decision speed with the landing gear extended while the aircraft was over the runway.
5. The pilot elected to continue the takeoff.
6. The aircraft was manoeuvred, including turns and banks, at low altitude resulting in a decrease in airspeed below that required to maximise one-engine inoperative performance.
7. The pilot was unable to maintain the aircraft's altitude over terrain that was unsuitable for an emergency landing.

4 SAFETY ACTION

4.1 Operator

Following this occurrence, the operator modified other C404 aircraft in its fleet to incorporate a warning light to indicate low fuel pressure. That modification incorporated part of the system originally installed to automate the switching of auxiliary pump speed.

4.2 Previous ATSB safety recommendations

On 25 June 2004, concurrent with the release of investigation report BO/200105618, the ATSB issued recommendations relevant to pilot training for engine-out operations in multi-engine aircraft. Those recommendations were also relevant to the circumstances of the occurrence involving ANV.

R20040069

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

CASA responded to that recommendation on 23 August 2004.

> *The training syllabus for the initial issue of a multi-engine aeroplane endorsement is currently published by CASA in Civil Aviation Advisory Publication (CAAP) 5.23-1. It describes in detail the course of flight and ground training, which candidates seeking their first multi-engine endorsement (rating) should undertake. The syllabus is also applicable to subsequent endorsements and provides the knowledge and training requirements that detail appropriate decision making procedures to be employed by pilots when responding to engine failures and other emergencies in multi-engine aircraft.*
>
> *For training in decision-making procedures, it is considered necessary to replicate as accurately as possible, the situation where an emergency could take place. In Australia, synthetic training devices for this class of aircraft are typically generic in nature and are seen as a useful aid in the training of emergency procedures.*
>
> *However, due to the lack of realism, it is considered that they fail to simulate the environment sufficiently to be of benefit in this type of human factors training. It should also be noted that there is a substantial cost involved in the acquisition and operation of synthetic training devices.*
>
> *Assessment of human factors is currently included in all pilot licence theory examinations and an assessment is made during flight testing. With the implementation of Civil Aviation Safety Regulation (CASR) Part 61, CASA will incorporate human factors training in the Manual of Standards (MOS) for all flight crew licences. Additionally, aspects of human factors are embedded within the MOS as 'Manage Flight' elements and provide for an assessment of the decision-making process and behaviour that must be achieved for the issue of a qualification.*

The ATSB has classified CASA's response 'Closed-Partially Accepted'.

R20040068

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

CASA responded to that recommendation on 23 August 2004.

> *CASA has reviewed this recommendation and considers it to be unrealistic given the large number of aircraft types involved and the sometimes unique characteristics and procedures associated with each type of aircraft. Plus there are a number of publications currently available dealing with multi-engine training and the factors to be considered by operators when developing procedures for responding to emergencies. In addition, operators are required to produce appropriate procedures manuals that are reviewed by CASA.*

The ATSB has classified CASA's response 'Closed-Not Accepted'.

4.3 Previous ATSB investigation

Following an occurrence at Bankstown Airport in November 2003, the Minister of Transport and Regional Services signed an Instrument of Direction for the ATSB to '…investigate the effectiveness of the fire fighting arrangements for Bankstown Airport, as they affected transport safety…'

Bankstown Airport is a General Aviation Aerodrome Procedures (GAAP) aerodrome which had similar provisions for aerodrome rescue and fire fighting services (ARFFS) to Jandakot Airport at the time of the occurrence involving ANV.

The ATSB report 200305496 is available on the ATSB web site www.atsb.gov.au

APPENDIX A – Technical Analysis Report

Examination of Engine-Driven Fuel Pump Units
Teledyne Continental Motors, GTSIO-520
Cessna Aircraft Company, Model 404 ‘Titan’,
VH-ANV
11 August 2003

Report No. 24/04

Task No. BE/200300022

Occurrence No. BO/200303579

CONTENTS

1 FACTUAL INFORMATION

1.1 Examination brief

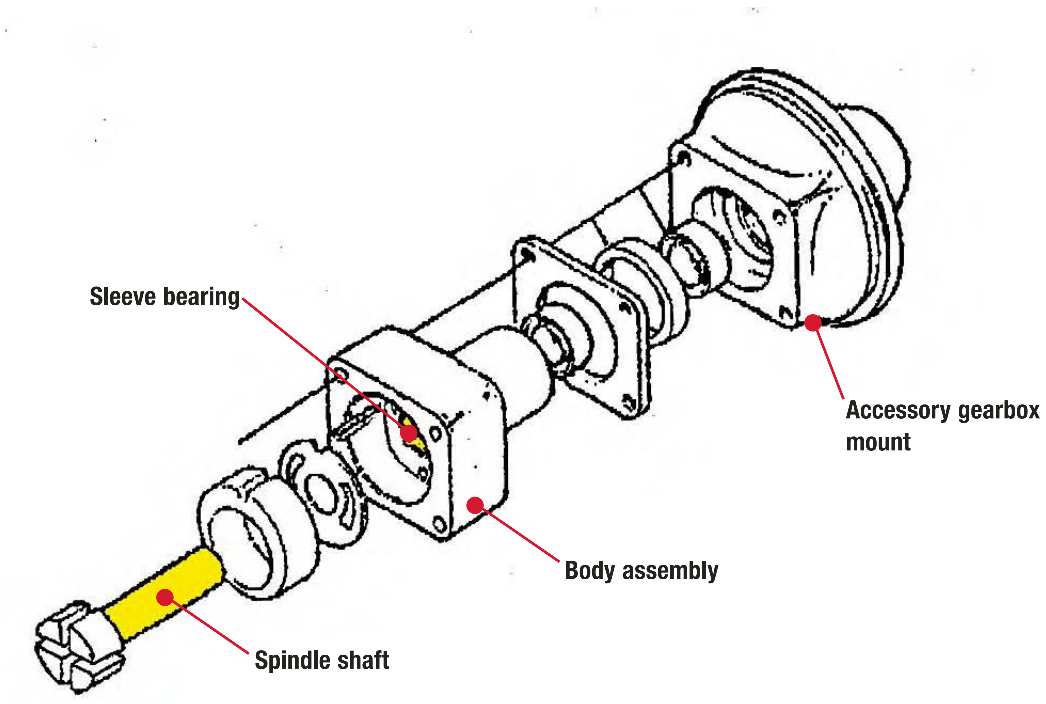
A Cessna Aircraft Company 404 Titan aircraft, registered VH-ANV, impacted terrain shortly after takeoff, during an attempt by the pilot to return and make an emergency landing. Impact forces and an intense post-impact fire destroyed the aircraft. The aircraft engines were amongst various items recovered from the accident site for examination.

Workshop examination of the engines and associated components revealed damage to the engine-driven fuel pump from the right engine. The pump, together with the pump from the left engine were subsequently submitted to the ATSB's Technical Analysis Laboratory for detailed examination and analysis.

1.2 Pump information

The engine-driven fuel pumps (EDFP) were rotary vane, positive-displacement types, each powered through the respective engine accessory drive and operating at engine output (crankshaft) speed (see Figure 1). The pump shafts were supported on a plain metal sleeve bearing and lubricated by fuel channelled from the pump chamber.

FIGURE 1: Basic EDFP assembly



Both left and right engine-driven pumps were identified from maintenance documentation as Teledyne Continental Motors part number 646210-3, with serial numbers and operational history as follows.

Right EDFP

Pump serial number K048931BR was installed onto the right engine of VH-ANV on 18 October 2000, as a locally overhauled (zero-time) item, and was due for removal after 1,600 hours of operation. The pump had been repaired during that overhaul in accordance with an engineering order (EO 6826-1), to replace the pump spindle bearing (bush) by removal and substitution. The engineering order specified that the replacement bearing be manufactured from an aluminium bronze material. Sleeve bearings are not normally replaced during pump overhaul - if unserviceable due to excessive wear or otherwise, the manufacturer provided for the replacement of the pump body as an assembly. The pump had subsequently accumulated 1,353.3 hours time since overhaul (TSO) at the time of the accident.

Left EDFP

Pump serial number K028729BR was installed onto the left engine of VH-ANV on 28 December 2001 as a low-time replacement assembly, having operated for 130 hours on a previous installation. At the time of the accident this pump had accumulated 643.7 hours TSO.

1.3 Visual examination

1.3.1 Right engine-driven fuel pump

The disassembled pump body with bearing insert, pump rotor and shaft, rotor vanes, liner and thrust plates, together with the accessory drive gear and shaft drive pin were supplied for examination.

Externally, the pump body displayed staining and discolouration consistent with the effects of the post-impact fire (see Figure 2). Where protected by its connection to the engine, the pump bearing housing was comparably free from the visible effects of the fire, with the flexible shaft end seal intact (see Figure 3).

FIGURE 2: Body assembly showing surface discolouration from the post-accident fire

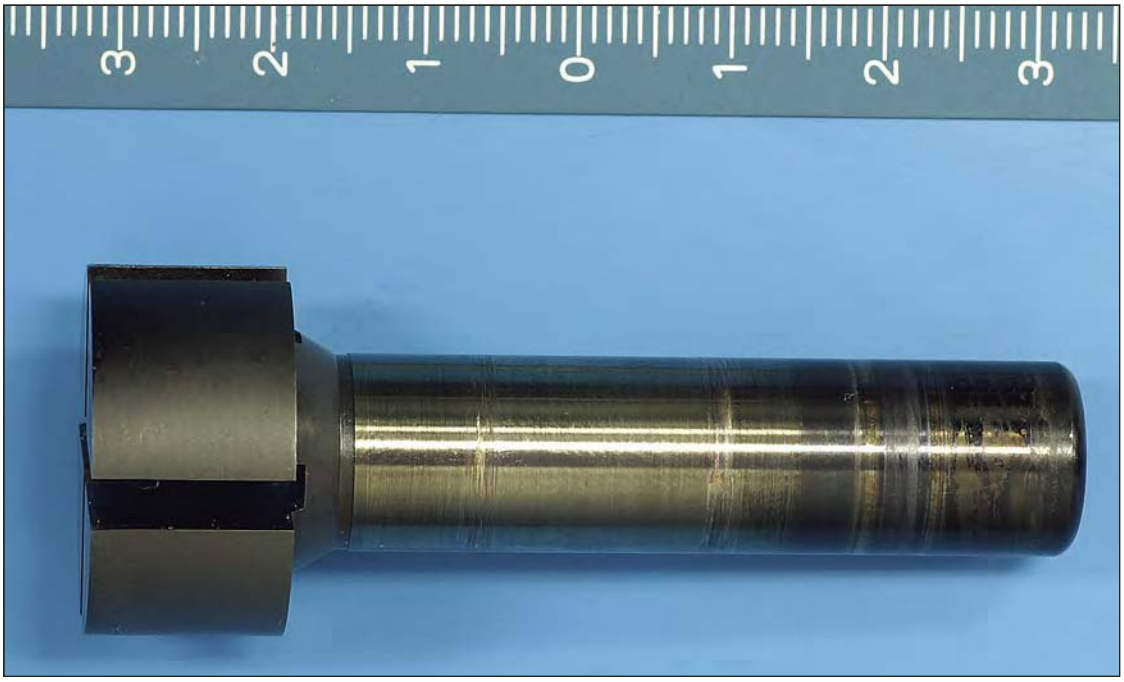
The pump rotor vanes, chamber liner and thrust plates were intact and in good condition, with no indications of excessive wear, seizure or other anomalous operation. There was no evidence of deposits, corrosion or other foreign matter within the pump chamber.

FIGURE 3: Spindle shaft end seal in good condition

Right pump shaft

The pump shaft (see Figure 4) exhibited some staining and blackening around the driven end and two circumferential bands of galling[47] and pick-up of metal from the sleeve bearing (see Figure 5). Between those areas, the shaft surfaces appeared sound and undamaged, with no other indications of anomalous operation.

FIGURE 4: Right EDFP spindle shaft, as removed from the pump body



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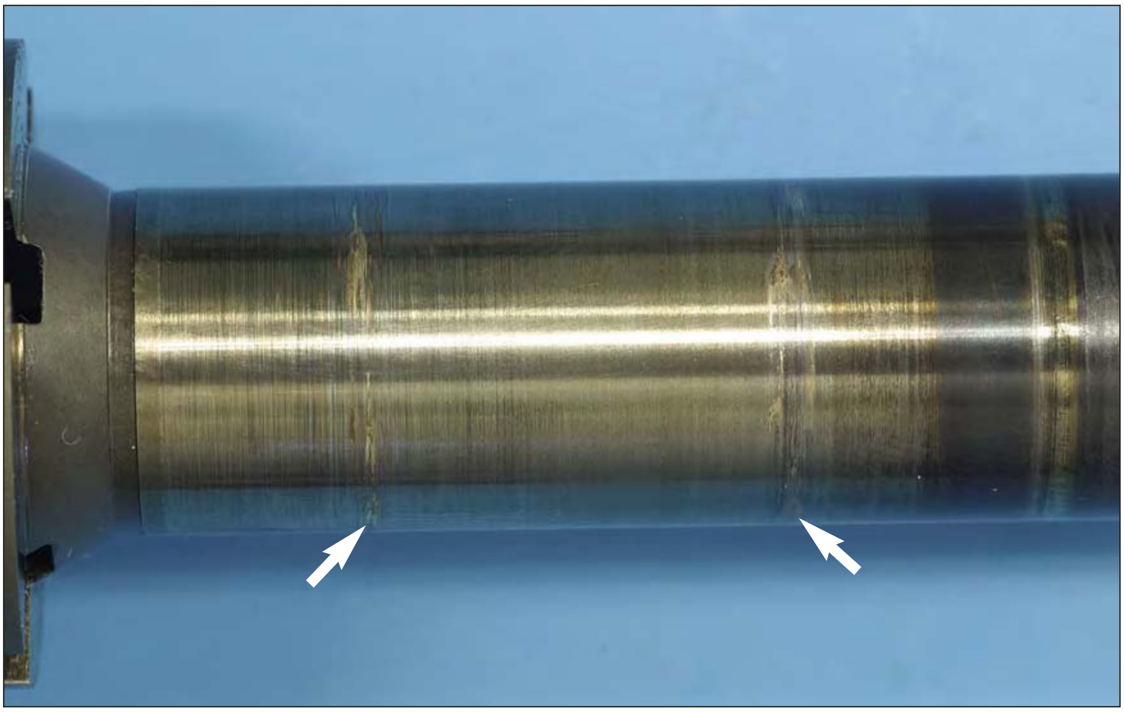
[47] Galling is a mechanism of adhesive wear and metal loss defined as "the welding of surface asperities due to frictional heat. The welded asperities subsequently break, causing surface degradation" (ASM Handbook, Volume 18, Lubrication and Wear Technology, page 16).

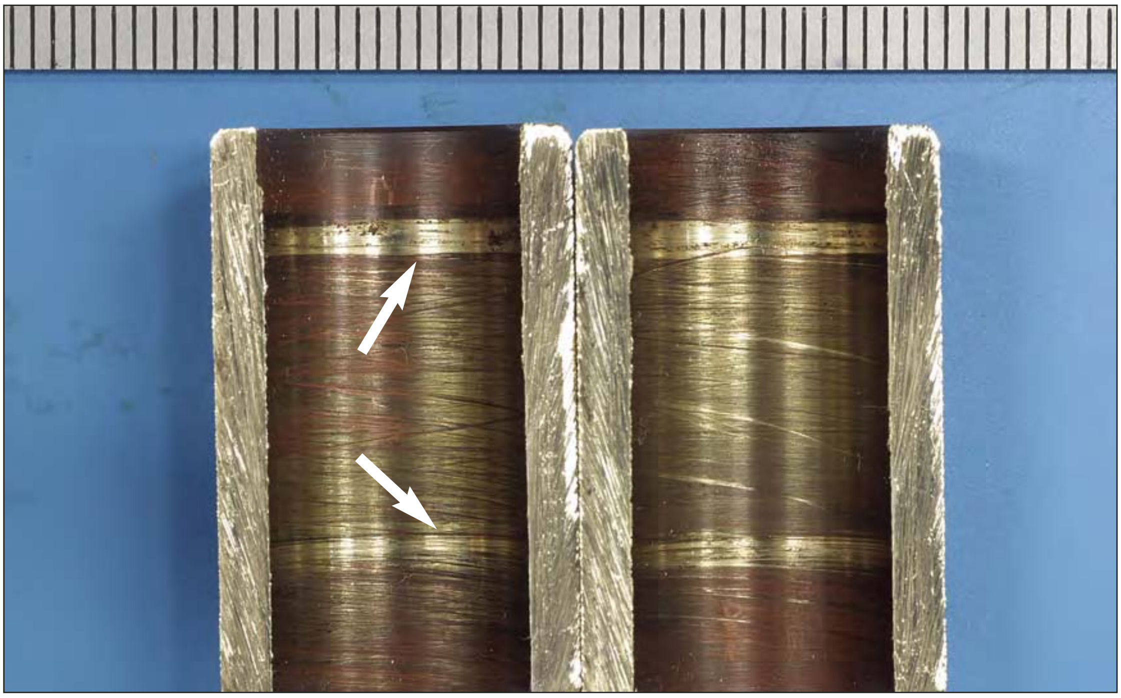
FIGURE 5: Right EDFP spindle shaft, with the two localised areas of galling damage indicated



Sleeve bearing

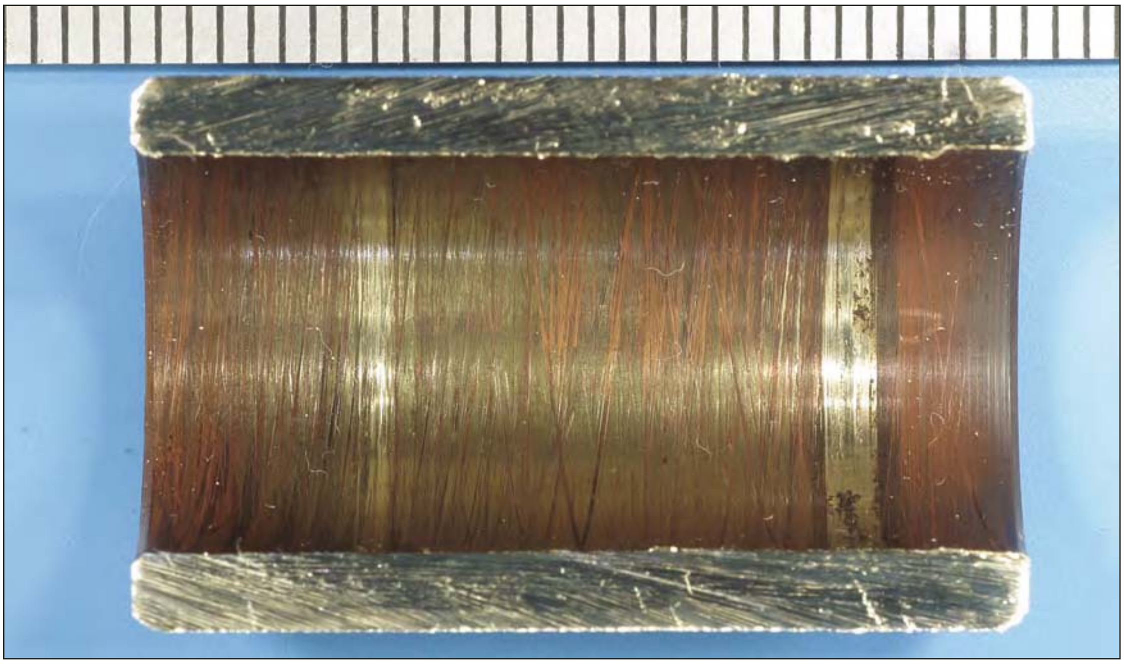
Removal and axial sectioning of the sleeve bearing revealed two bands of galled and polished material that corresponded with the galled areas identified on the surface of the spindle shaft (see Figure 6). Both bands were localised and equidistant from the inner and outer ends of the sleeve bearing. The internal running surfaces of the sleeve bearing presented a generally coarse, spiral honed finish with a pronounced copper colouration between the galled bands (figure 7).

FIGURE 6: Right EDFP sleeve bearing, sectioned to show the internal condition



Note the polished bands corresponding with the areas of galling on the spindle shaft

FIGURE 7: Right EDFP sleeve bearing half showing the general coarse honed surface finish

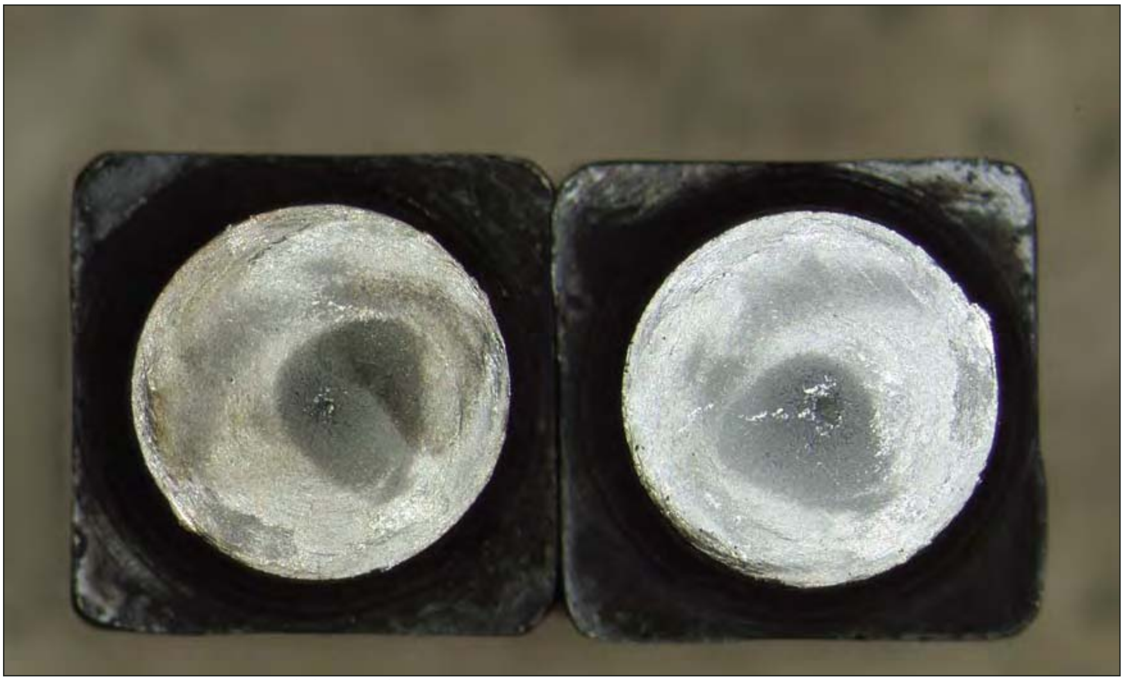


Shaft drive pin

The fuel pump was coupled to the engine through a square drive pin that contained a central reduced section shear point (see Figure 8). That shear point was designed to protect the engine accessory drive train from damage by disconnecting the pump in the event of any failure that increased pump drive loads. Examination of the drive pin indicated that it had failed transversely through the shear point and exhibited uniform fracture surfaces. Low-power microscopic study of the fractures revealed a faint light brown staining on the pin half that originated on the pump-side of the drive connection (see Figure 9), with similar staining noted on the sides of the pin that protruded from the pump shaft when installed on the engine (see Figure 10). The staining and discolouration was notably absent on those surfaces of the pin that were engaged within or otherwise protected by the coupling assembly (see Figure 11).

FIGURE 8: Fractured drive pin as recovered from the right EDFP

FIGURE 9: Fracture surfaces of the drive coupling



Note the light staining over the left fracture features

FIGURE 10: Staining and discolouration on the sides of the drive coupling

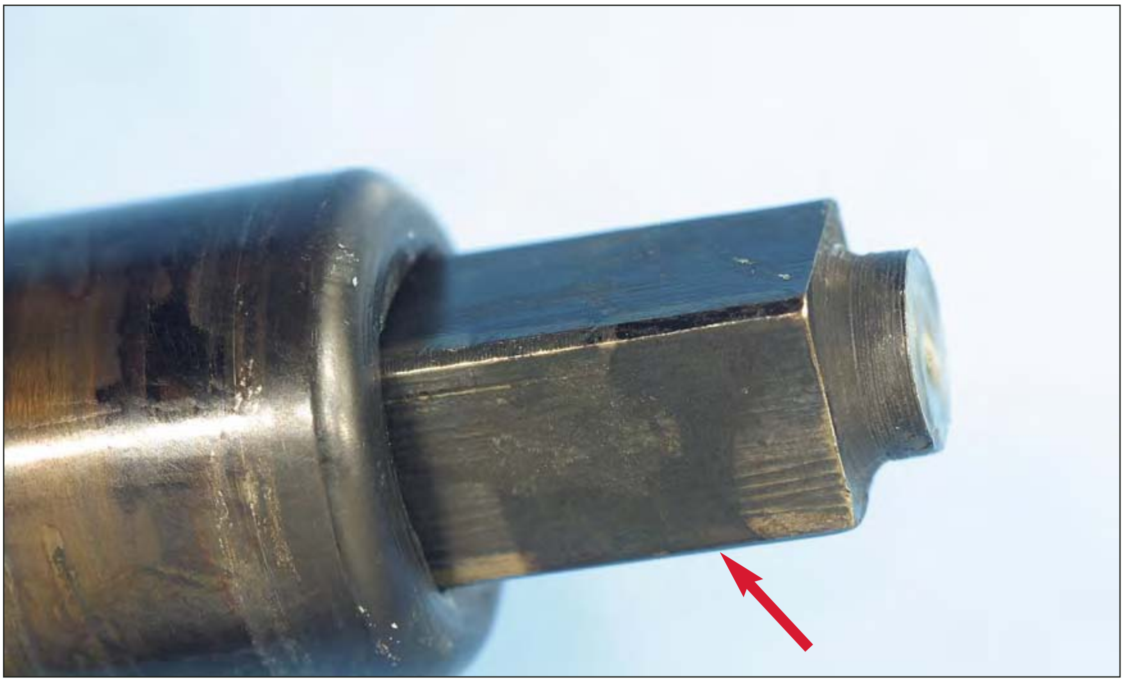


FIGURE 11: Drive coupling engaged with the accessory drive gear

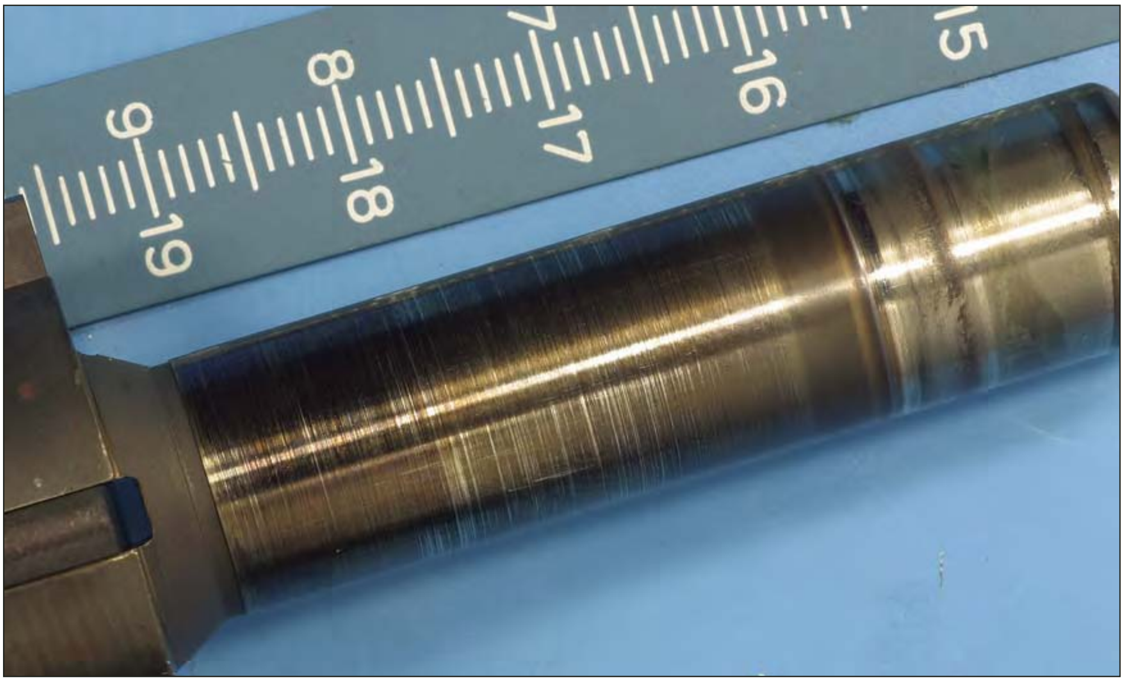
1.3.2 Left engine-driven fuel pump

The basic components from the left EDFP were examined and compared with the components from the right EDFP. Components from the left pump generally exhibited greater evidence of heating and discolouration from the post-impact fire, particularly in regard to the discolouration and tinting of the pump shaft and associated components. The pump vanes, thrust plates and chamber liner were intact and in a similar condition to the items from the right EDFP. None of the components showed any mechanical damage, distress or features that may have suggested anomalous operation or the ingress of foreign materials or contaminants.

Sleeve bearing and spindle shaft

The left spindle shaft and its associated sleeve bearing displayed no galling or characteristics of adhesive wear. The shaft surface, although moderately discoloured, was physically sound and smooth across the full running width. Light scoring of the discoloured shaft surface suggested some rotation of the assembly after the fire event (see Figure 12), possibly during the engine disassembly or post-accident functional testing of the pump. The sleeve bearing exhibited circumferential polishing and light wear around one side of the bore, with the opposing internal faces displaying the light dimpled texture often associated with glass bead blasting of lower hardness metallic materials. There was no evidence of excessive friction or overheating within the shaft bearing space.

FIGURE 12: Left EDFP spindle shaft with light scoring, but no surface galling or pickup

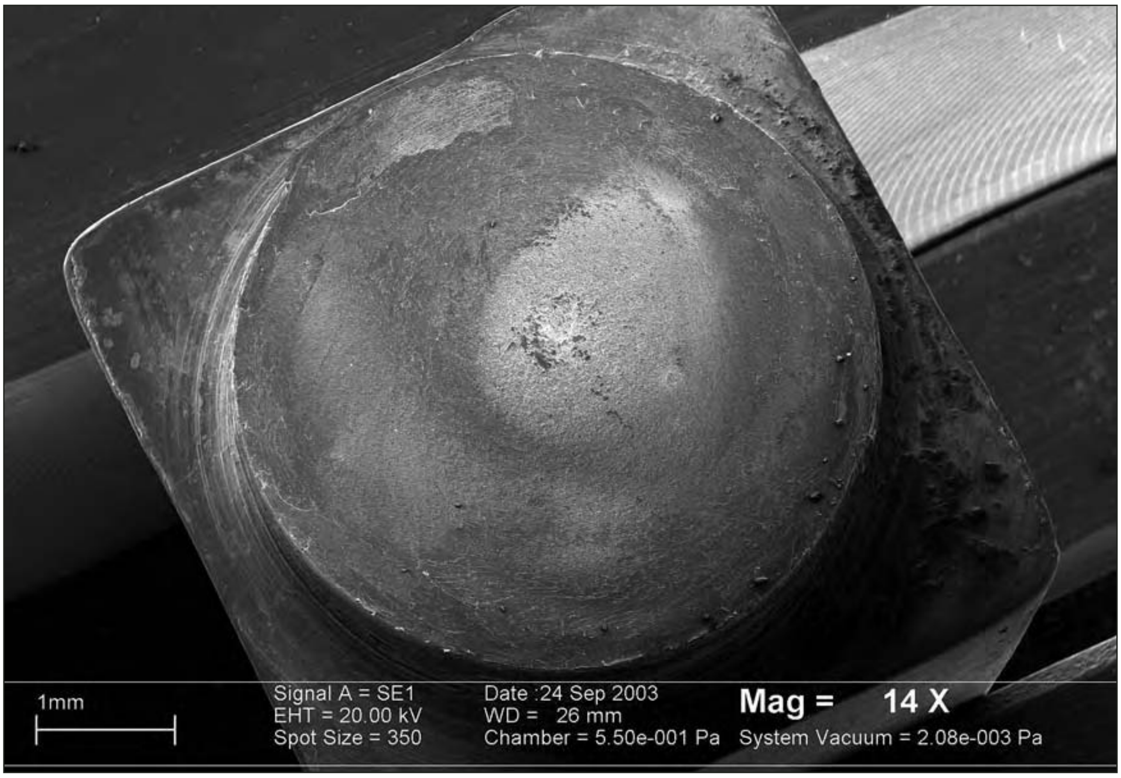


1.4 Surface characterisation

Drive pin fracture – right pump

The opposing fracture surfaces of the failed drive pin from the right engine pump were examined under the scanning electron microscope (SEM) to characterise the fracture form and the visible surface staining. The physical fracture features were typical of axial torsional overload, exhibiting a peripheral zone with ductile shear characteristics. This was surrounded by a central region of typically ductile tensile overload morphology (see Figure 13).

FIGURE 13: SEM image of the drive coupling fracture surfaces – features typical of torsional shear overload



Energy-dispersive x-ray spectroscopy (EDS) was used to analyse the surface staining and discolouration observed on the surfaces of the drive pin.

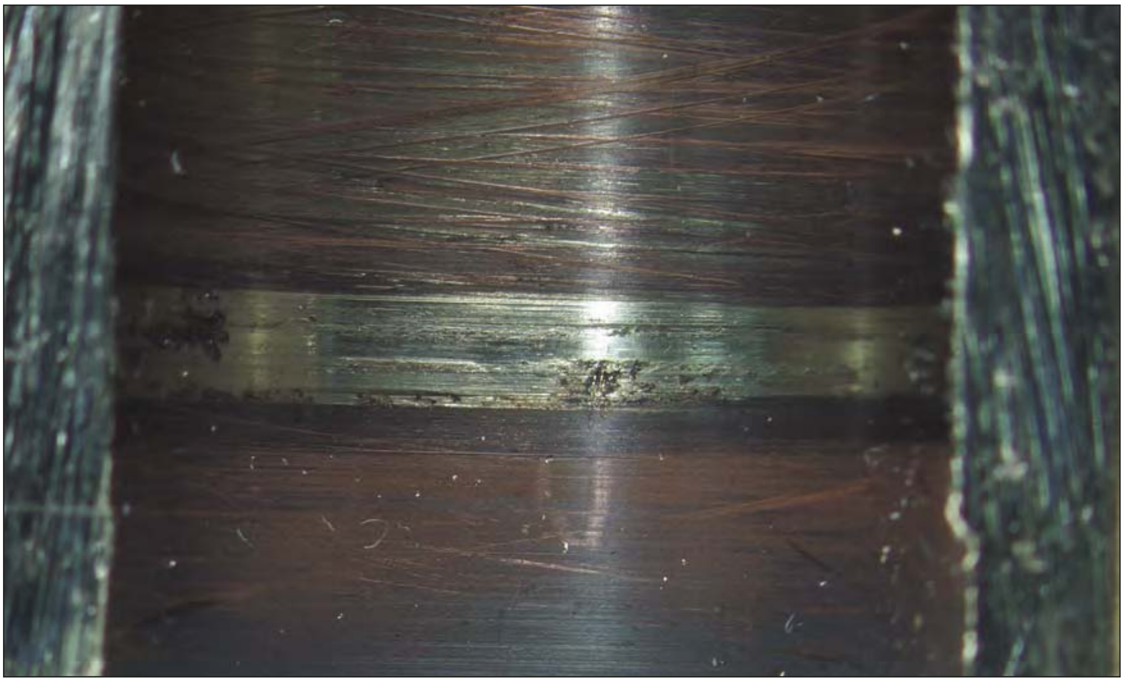
	Major Elements Identified	*Minor Elements Identified*
Surface Deposit	Carbon (C)	Sodium (Na)
	Bromine (Br)	-
	Lead (Pb)	-
	Oxygen (O)	-
	Iron (Fe)	-
Stained Fracture	Iron (Fe)	Chromium (Cr)
	-	Lead (Pb)
	-	Bromine (Br)
	-	Carbon (C)
Clean Fracture	Iron (Fe)	Chromium (Cr)
	-	Lead (Pb)
	-	Bromine (Br)
	-	Carbon (C)

Of the elements identified, iron (Fe) and chromium (Cr) were most likely to have originated from the base metal (steel) of the drive pin. Contrastingly, bromine (Br) and lead (Pb) are typically foreign to steel, however both elements are present in aviation gasoline fuels. Compounds of lead, bromine, oxygen and carbon form during combustion of those fuels and may be deposited on surfaces exposed to the combustion gases, particularly if the combustion conditions were not optimum.

Surface galling of spindle shaft and sleeve bearing – right pump

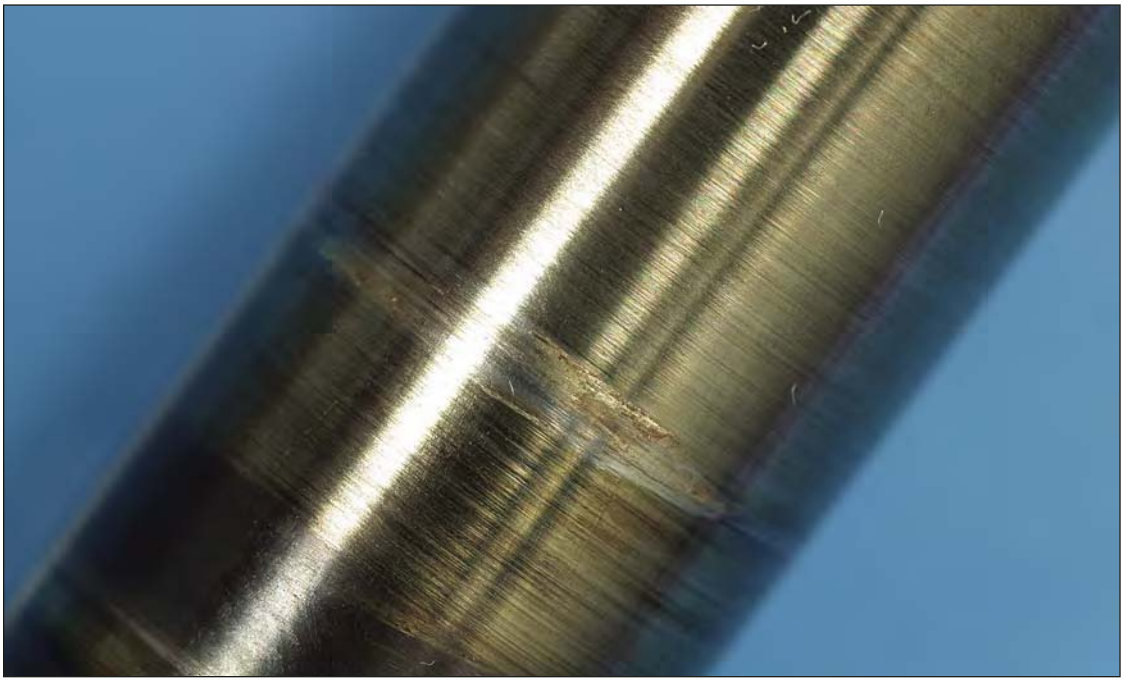
The localised areas of galling damage shown by the spindle shaft and sleeve bearing were examined optically and under the SEM. Under the optical stereomicroscope, the galled regions of the spindle shaft exhibited the circumferential ductile flow of adherent material and were typical of the damage incurred during shaft rotation (figures 14, 15).

FIGURE 14: Close view of the localised damage exhibited by the right EDFP sleeve bearing



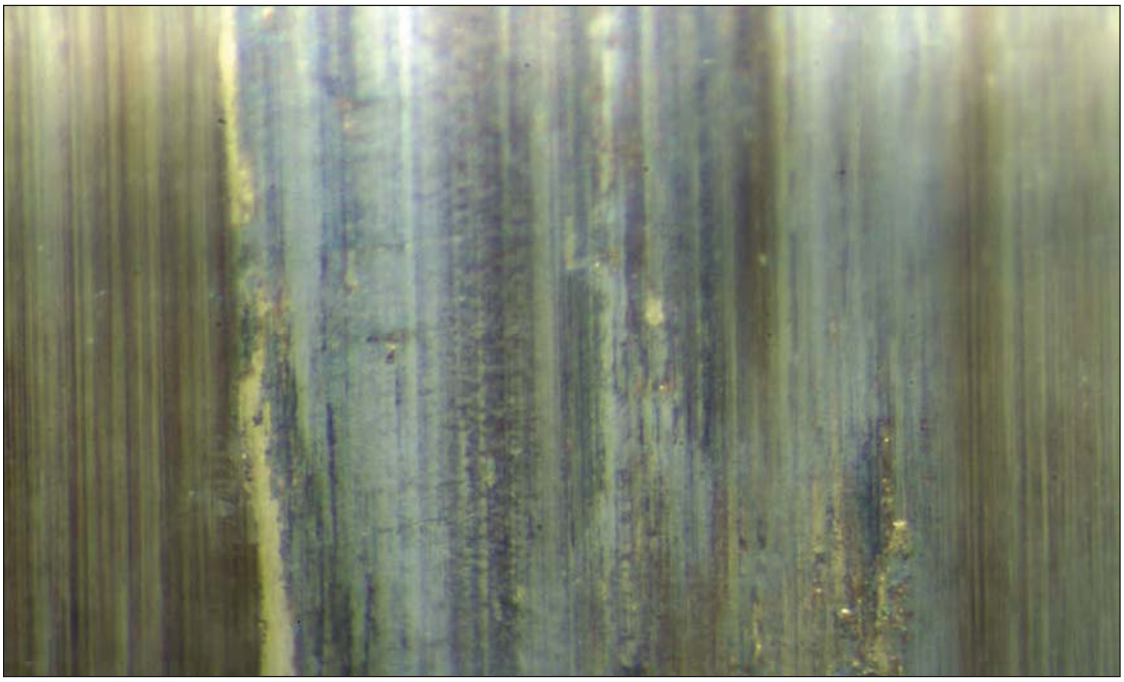
Note the circumferential flow of the polished band

FIGURE 15: Right EDFP spindle shaft damage corresponding to the area shown in Figure 14



Closer inspection revealed indications of multiple, regularly spaced cracks extending across some of the more heavily galled areas (see Figure 16), with an associated general surface discolouration, typical of frictional heat tinting.

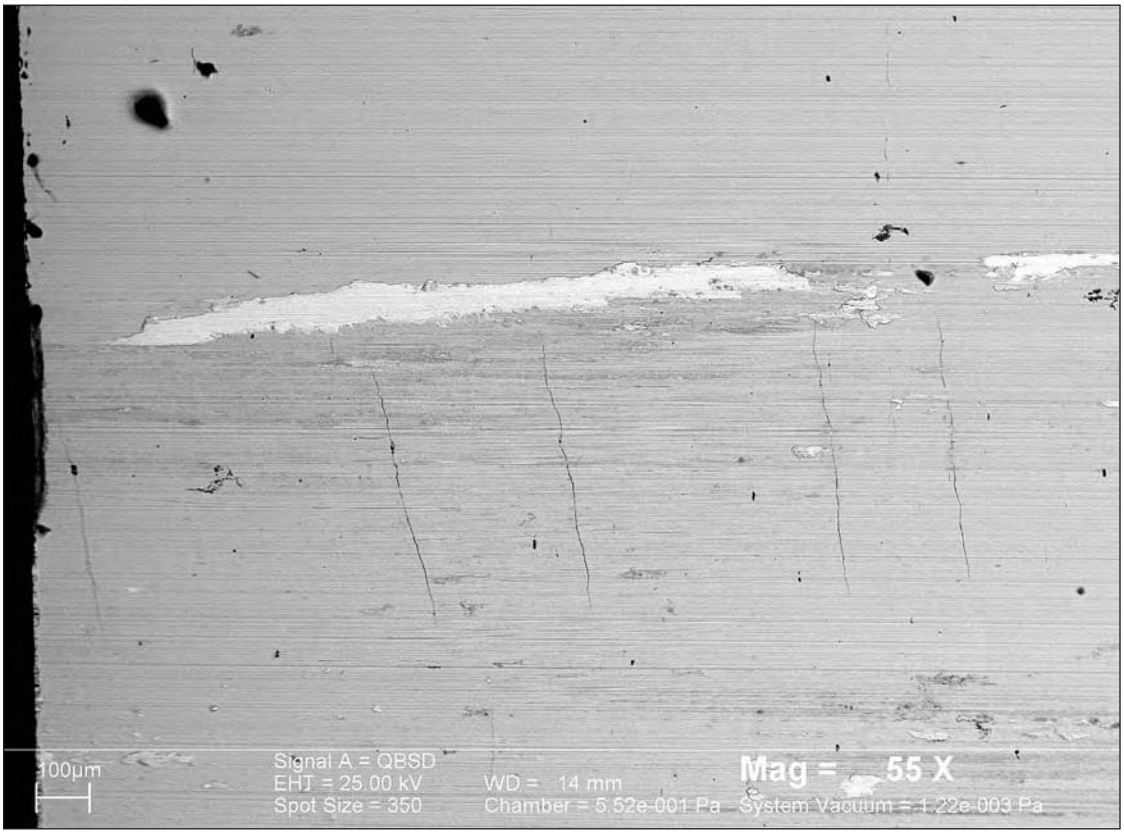
FIGURE 16: Low power optical microscope view of the damaged area shown above



Note the discolouration effects typical of frictional heating

The presence of surface cracking was confirmed when examined under the SEM (see Figure 17), with the regularity in spacing and length of the cracks indicating their formation as thermal 'checks' i.e. stress relief cracks formed as a consequence of localised thermal heating and cooling of brittle materials.

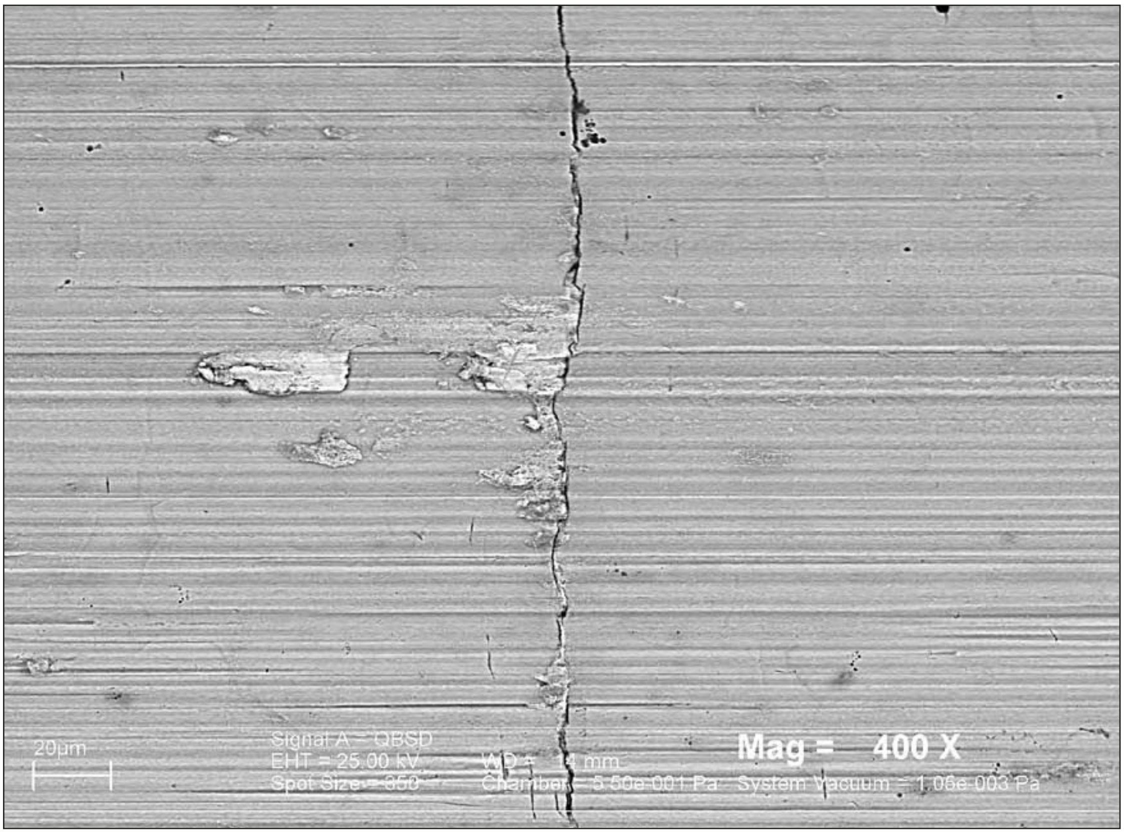
FIGURE 17: Electron microscope image of the area above



Note the characteristic thermal stress relief cracks running across the area of galling damage

At higher magnifications, several of the cracks displayed the pickup and adhesion of bearing material intermittently along the crack length (see Figure 18).

FIGURE 18: Higher magnification SEM view of a thermal crack in the spindle shaft



Note the collection and pickup of material within the crack

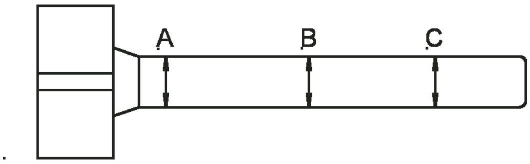
All of the cracks observed were confined to the areas of shaft surface galling and distress and did not extend onto the adjacent unaffected surfaces.

The internal (running) surfaces of the sleeve bearing were examined at a range of magnifications. That examination did not detect any evidence of hard particle contamination or other foreign abrasive materials that could have contributed to the development of the galling damage. The internal surface showed a coarsely honed finish, with the angular, scoring typically associated with the honing process.

1.5 Dimensional examination

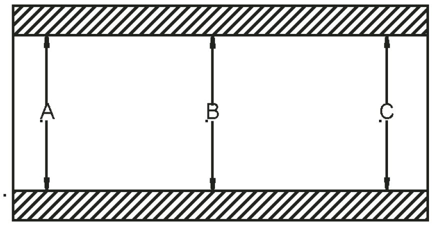
Prior to removing the sleeve bearings from the pump bodies for further study, the dimensions of the sleeve bearings and spindle shafts were measured and compared with the original equipment specifications.

Spindle shafts



	Diameter measurement at position (inches)		
	A	B	C
Right pump	0.49955 - 0.49955	0.49945 - 0.49945	0.49940 - 0.49945
Left pump	0.49930 - 0.49935	0.49925 - 0.49935	0.49935 - 0.49940
Specification[48]		0.49940 - 0.49970	

Shaft sleeve bearing



	Bore measurement at position (inches)		
	A	B	C
Right pump	0.50045 - 0.50055	0.50005 - 0.50020	0.50000 - 0.50000
Left pump	0.50290 - 0.50900	0.50025 - 0.50115	0.50130 - 0.50150
Specification		0.50000 - 0.50020	

Both spindle shafts were dimensionally comparable, with both within or only marginally below the new part specifications. In contrast, the sleeve bearings exhibited an appreciable difference and variability in bore diameters. The left pump sleeve was up to 0.0088” (0.22 mm) above the maximum specified diameter along the full length, whereas the right pump sleeve was 0.00035” (0.0089 mm) above specification in one location.

---

[48] Teledyne Continental Motors Engine Maintenance Manual, 73-40-04 ‘Fuel Pump Assembly’, table III, new part dimensions.

1.6 Chemical analysis[49]

Sub-samples of the shaft sleeve bearings from the left and right engine driven fuel pumps were spectrographically analysed to identify the bearing alloy composition and alloy type.

	Elemental composition, weight %												
Pump	Cu	Si	Fe	Zn	Pb	Cr	Ni	Mn	Sn	Al	P	As	Sb
Left	~Bal	<.01	<.01	.10	22.9	<.01	.28	<.01	4.91	<.01	.07	.02	.16
Right	~Bal	.04	4.04	.14	.02	<.01	1.18	.13	.02	10.3	<.01	<.01	<.01

The analysis indicated that the sleeve bearings of the right and left pump shafts were produced from different alloy types. The left pump (understood to be an original equipment item), utilised a 'high leaded bronze' type alloy for the sleeve bearing; the alloy being generally compliant with the chemistry specifications for a UNS[50] C94300 cast Cu-Pb-Sn material. Analysis of a similar EDFP bearing from another aircraft confirmed the use of this alloy type.

The sleeve bearing from the right pump was confirmed as an aluminium bronze alloy as specified in the Engineering Order for the sleeve replacement during the previous overhaul. The material met the general chemical composition requirements for a UNS C95410 Cu-Al-Fe-Ni alloy.

1.7 Metallographic (microstructural) examination

Specimens suitable for microstructural study were prepared from the sleeve bearings of the left and right pumps and the right spindle shaft in the damaged areas.

Sleeve bearing – left pump

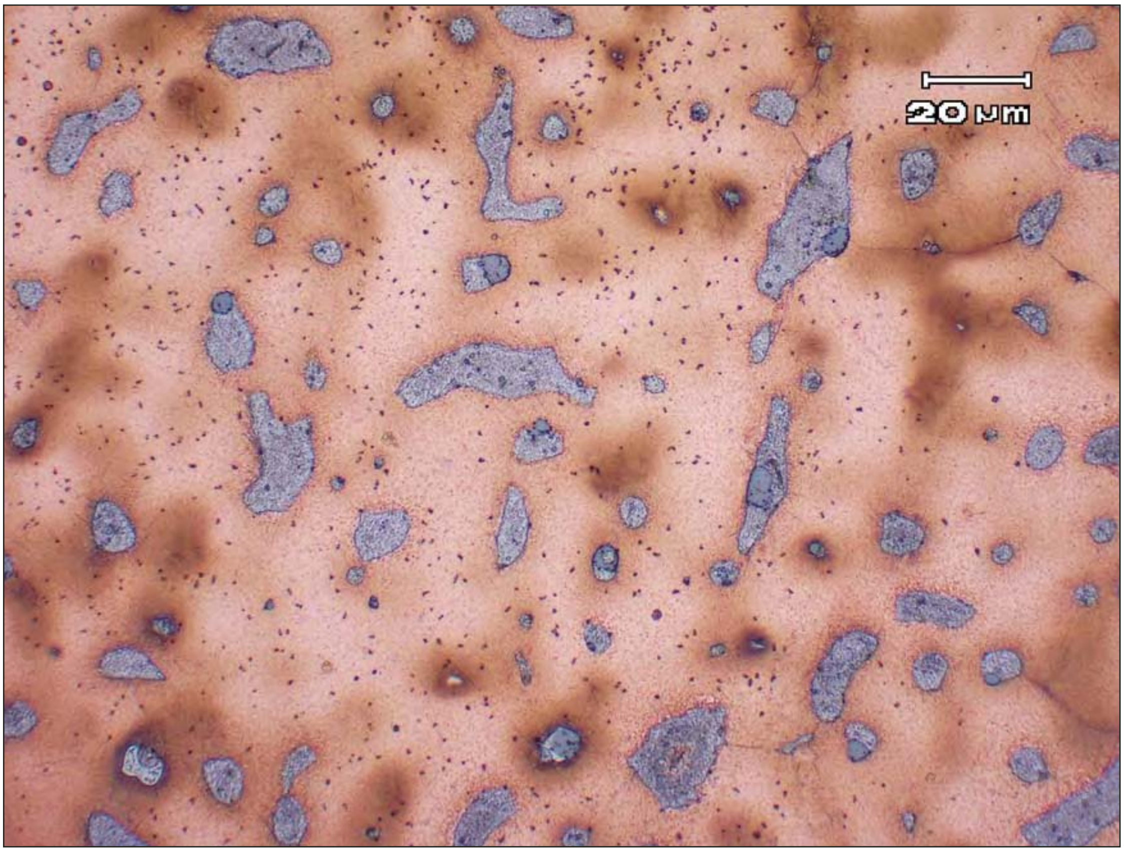
In the unetched condition, the sleeve alloy from the left pump exhibited a two-phase microstructure consisting of coarse distributed islands of lead within a copper-tin matrix. Etching in an acidified alcoholic ferric chloride solution revealed a dendritic morphology within the matrix; typical of the alloy being produced as a cast product (see Figure 19).

---

[49] Analysis conducted by Spectrometer Services Pty Ltd, Coburg Victoria (Report No's: 15773, 15814).

[50] Unified Numbering System.

FIGURE 19: Characteristic microstructure of the high leaded bronze material making up the sleeve bearing for the left pump[51]



Sleeve bearing – right pump

As suggested by the differences in chemical composition between the two bearing sleeves, the sleeve alloy from the right pump presented a characteristically different microstructure. When etched in acidified alcoholic ferric chloride, the microstructure showed a moderately coarse distribution of widmanstatten alpha phase (α), within a beta phase (β) matrix (see Figure 20). The structure was uniform throughout and typical of an as-cast aluminium bronze alloy of the composition identified.

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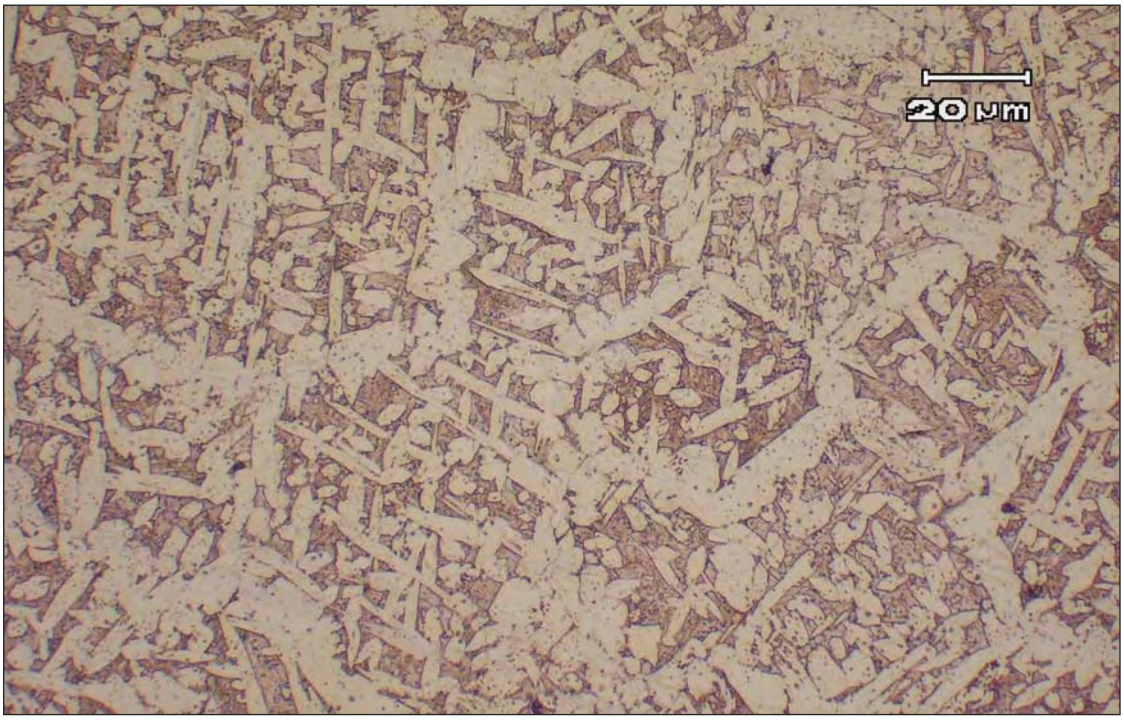
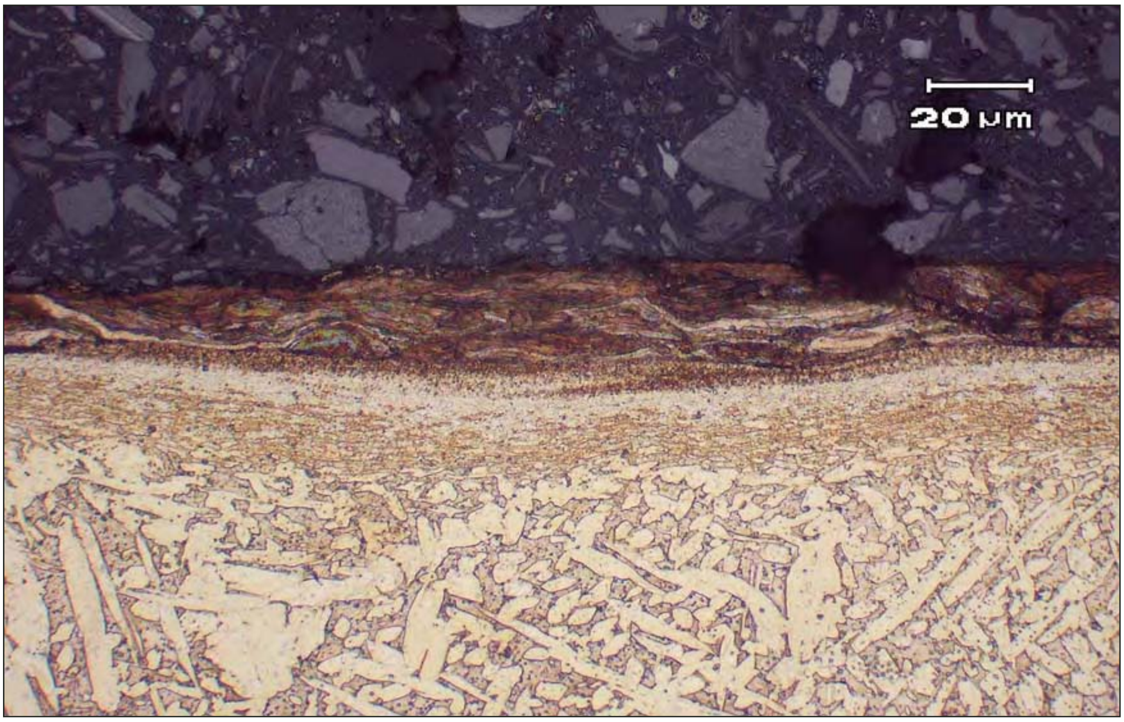
[51] The structure consists of lead rich islands within a copper-tin alloy matrix – Acidic ferric chloride etch.

FIGURE 20: Characteristic microstructure of the aluminium bronze material making up the sleeve bearing for the right pump[52]



The areas of galling and seizure at the running surface of the bearing were characterised by a twenty micron deep layer of heavily flowed and worked alloy, above a similar thickness of compressively distorted grains with some evidence of partial thermally induced microstructural transformation (see Figure 21).

FIGURE 21: Microstructural cross-section through a damaged area on the sleeve bearing surface[53]



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[52] A two phase structure of acicular widmanstatten α within a β matrix - Acidic ferric chloride etch.

[53] Acidic ferric chloride etch.

Spindle shaft – right pump

Transverse and longitudinal metallographic specimens were taken from the right pump spindle shaft to characterise the effects of the galling damage and the general nature of the shaft production. The bulk (core) of the shaft presented with a uniform tempered bainitic microstructure (see Figure 22), which transitioned to a shallow darker etching surface layer with fine intermittent grain boundary networks of a second phase (see Figure 23). The structures observed were consistent with the shaft having undergone a nitriding or similar surface hardening heat treatment.

FIGURE 22: Core microstructure of the right EDFP spindle shaft[54]

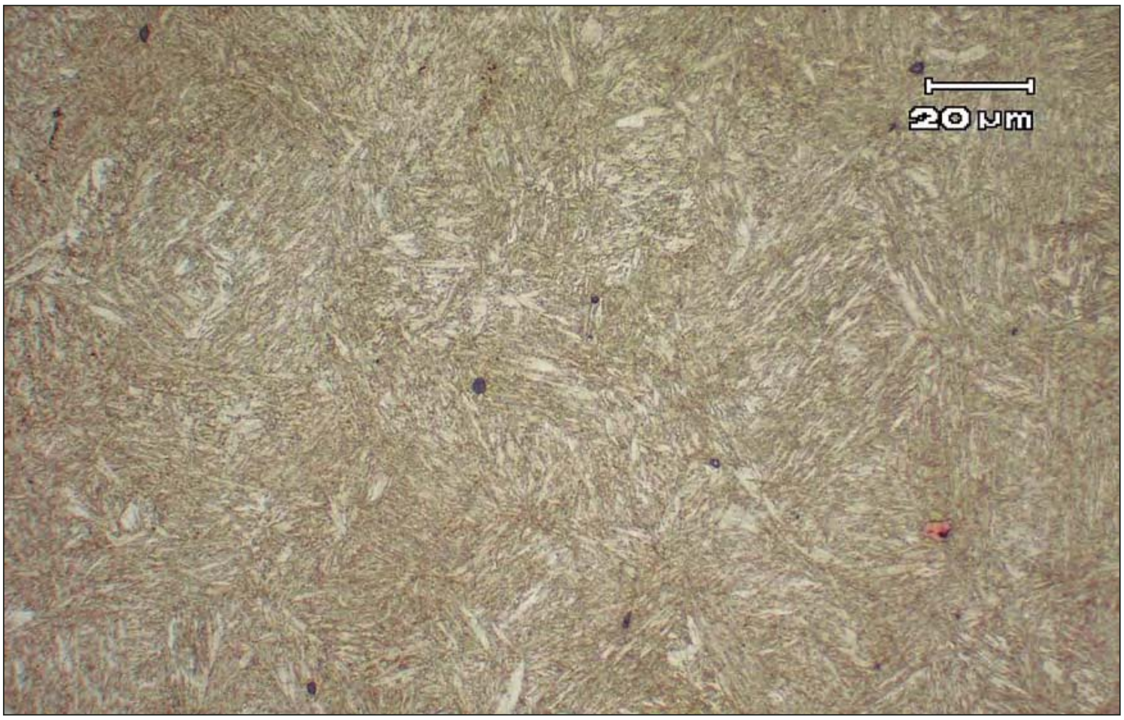
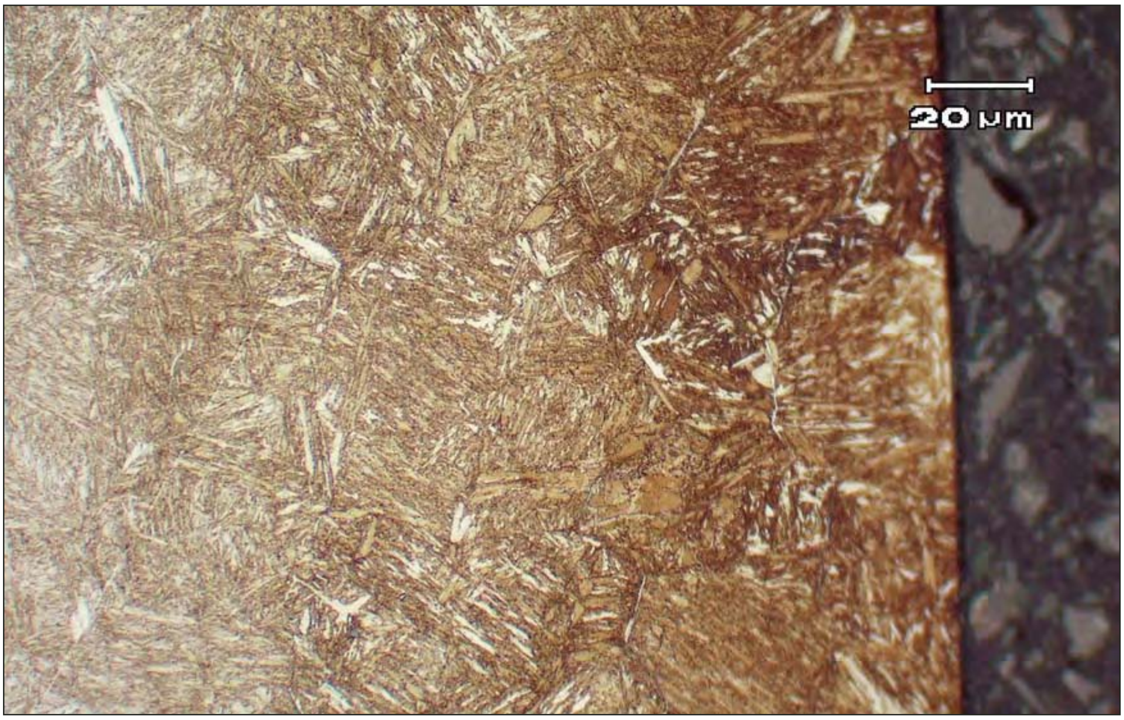


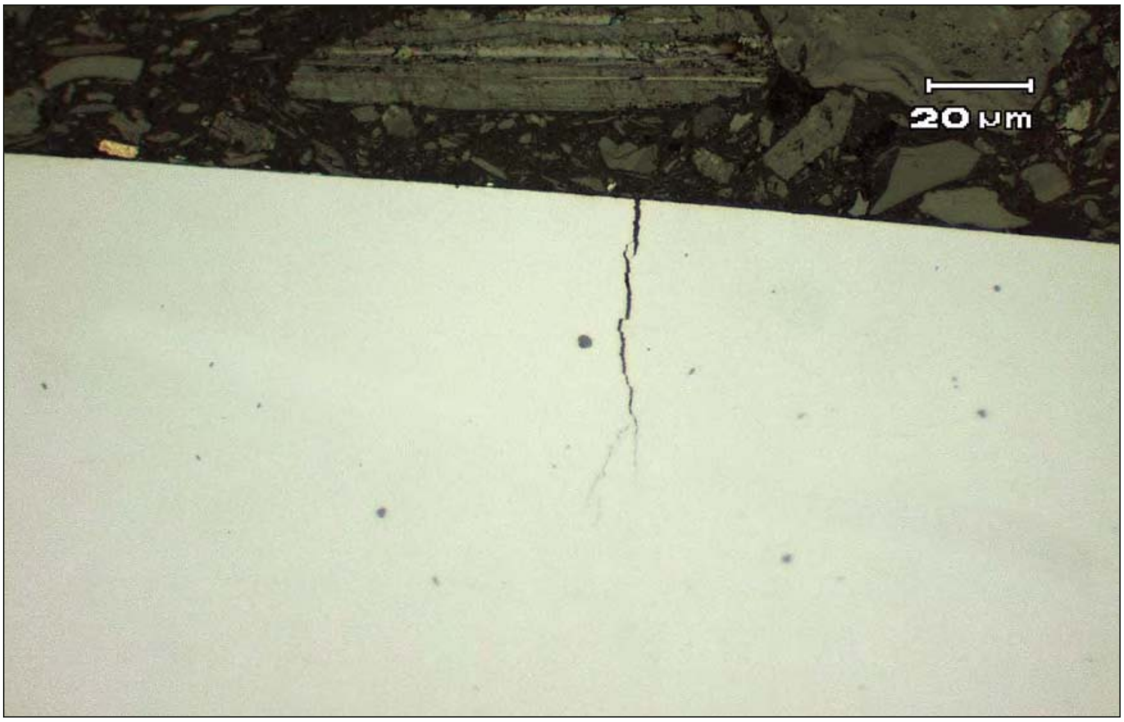
FIGURE 23: Surface microstructure of the right EDFP spindle shaft[55]



The transverse section through the galled surface areas confirmed the presence of the surface cracking as observed under the SEM. Several shallow cracks were observed (see Figure 24), extending to a typical depth of around 40 to 50 µm. Those cracks were contained entirely within the darker etching, surface-hardened layer (see Figure 25). In some areas, the cracking showed intergranular propagation.

Electron microscopy of areas that had sustained partial seizure and surface damage showed a 5 to 10µm deep surface layer of the bronze alloy, which had been galled away from spindle bearing (see Figure 26).

FIGURE 24: Cross section through the area of thermal cracking on the surface of the right EDFP spindle shaft [56]



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54 Uniform tempered bainite throughout - 1% Nital etch.

55 Tempered bainite with a network of suspected iron nitride, typical of a nitriding heat treatment for surface hardening purposes - 1% Nital etch.

56 Unetched.

FIGURE 25: Etched cross section through the area of thermal cracking on the surface of the right EDFP spindle shaft[57]

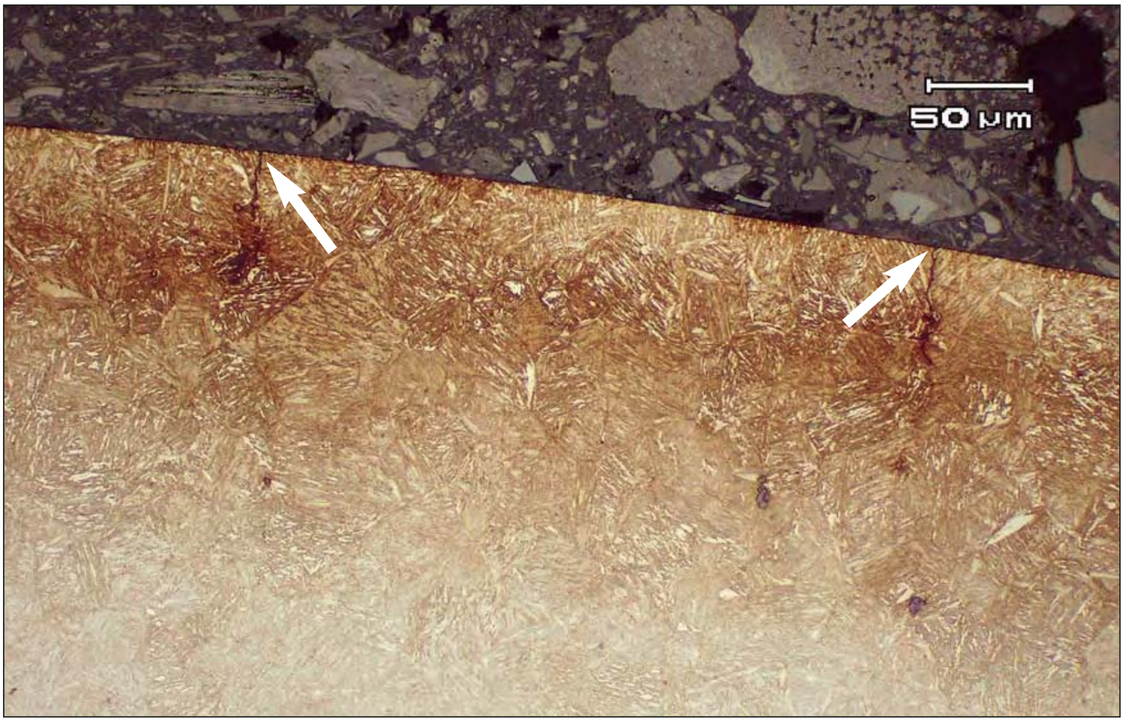
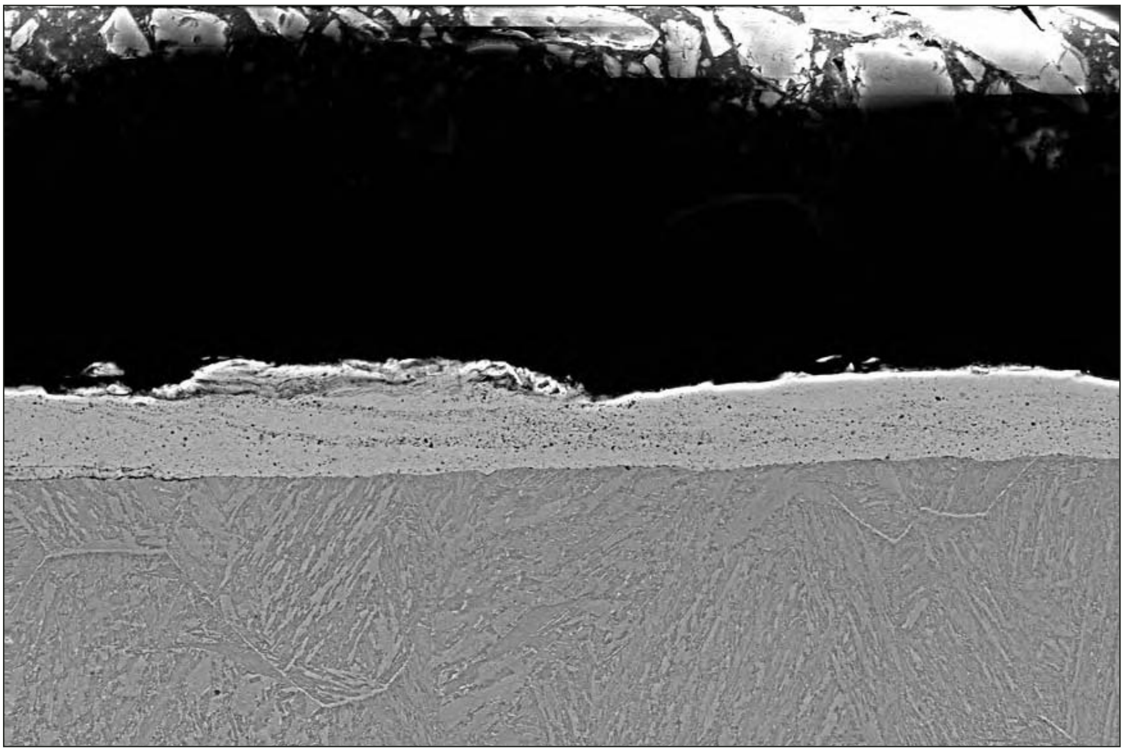


Figure 26: Electron microscope image of the surface of the spindle shaft, showing the adhesion and pickup of bronze alloy from the sleeve bearing



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[57] Cracking arrowed - 1% Nital etch

1.8 Hardness tests

A series of hardness tests were used to characterise and compare the general physical nature of the left and right sleeve bearings, the pump drive pins and the right pump spindle shaft.

Sleeve bearings

Conventional Vickers diamond-pyramid hardness tests conducted on the bulk sleeve material returned contrasting results, further demonstrating the differences between the alloys used.

	Hardness Vickers (HV_{10})
Left sleeve bearing (high leaded bronze alloy)	49 - 57
Right sleeve bearing (aluminium bronze alloy)	190 - 193

Drive pins

Vickers hardness tests were made on the square section surface of the pins from the left and right pumps and an exemplar item obtained from another assembly.

	Hardness Vickers (HV_{30})
Left drive pin (intact item)	381 - 385
Right drive pin (failed item)	462 - 467
Exemplar (for comparison)	413 - 418

Right pump spindle shaft

A through-section micro-vickers hardness traverse was used to determine case depth and heat treatment condition of the right pump spindle shaft.

Depth below running surface (mm)	Hardness Micro-Vickers ($HV_{0.1}$)
0.05	1026
0.10	755
0.15	629
0.20	449
0.25	412
0.30	394
0.35	384
0.40	400
0.45	395
0.50	396

The surface hardness values and profile to depth thus determined were typical of the spindle shaft having undergone a nitriding or comparable surface hardening heat treatment process during manufacture; substantiating the observations from the metallographic examination (section 1.7 of this appendix).

1.9 Sleeve bearing operation

Sleeve bearings of the type used by the EDFP spindle assembly are a common form of plain metal journal bearing with wide engineering application. For reliable, low friction operation, the bearings rely on the formation of a fluid film between the sliding surfaces, rather than the rolling movement of intermediary elements (eg. ball bearings). The formation of that film is dependant on the bearing physical design, speed of rotation and viscosity of the lubricating fluid.

The journal bearing has three modes of operation[58] that reflect the behaviour of the fluid film.

Boundary lubrication

This mode takes place when the sliding surfaces are rubbing, in direct contact or with only a very thin film of lubricant present. It is typically the dominant mode of operation of slow-moving bushes and oscillating bearings such as found on earthmoving equipment. The lubricant is usually heavy grease.

Hydrodynamic lubrication

Sometimes referred to as 'full film' lubrication, this mode produces a complete physical separation of the sliding surfaces and correspondingly low friction and wear characteristics. The mode relies upon comparatively high surface velocities, appropriate lubricant viscosity and flow, and suitable journal surface finishes and clearances.

Mixed film lubrication

An intermediary mode where there is partial separation of the sliding surfaces by the lubricant film. It is typically a transitionary mode experienced during start-up or shut-down of equipment that normally operates under hydrodynamic lubrication conditions.

The engine-driven fuel pump spindle, running at high speeds under light loads, was designed to operate under hydrodynamic lubrication, using pressurised fuel from the pump chamber as the lubricant between the pump spindle and the sleeve bearing. It is important to note however, that in starting up and accelerating to operating speed, the fuel pump spindle and sleeve bearing would pass through the boundary and mixed film modes before reaching the full film state. Fuel supplied during pre-start priming of the engine may provide some buffer against early boundary lubrication conditions, however the continuity of fuel flow sufficient to maintain hydrodynamic lubrication would not be expected until the engine had started and was operating normally. It is for those reasons that the selection of bearing materials (with regard to their physical properties) was important, if long term operational stability and reliability was to be assured.

1.9.1 Bearing materials

For a plain journal bearing to operate successfully, the bearing material must be selected with a view to the lubrication mode/s likely to be encountered during operation.

As the EDFP bearings do not have a separate or pressurised lubrication system, a full flow of lubricant (fuel) through the bearing will be only achieved once the pump is running and at operating pressure. The start-up period will thus be one of boundary and mixed film lubrication. Under those conditions, the inherent lubricity of the bearing material itself is relied

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[58] *Machinery's Handbook* 27th Edition, Industrial Press, Inc, pp. 2222.

upon to prevent scoring, galling or excessive wear. Interruptions to normal fuel flow, such as may be sustained during in-flight engine failure drills or inadvertent fuel starvation would also necessitate good bearing lubricity, if damage to the pump bearings was to be avoided.

Sleeve and journal bearings are typically produced from a wide variety of materials, however classes of the copper-based *bronzes* have traditionally found application in the type of spindle bearing employed by the engine-driven fuel pumps. The softer cast bronzes with high lead content (high leaded bronzes) contain globules of free lead throughout the microstructure, which tend to smear out over the surfaces during times of metal-to-metal contact (boundary lubrication), reducing friction and inhibiting galling and surface damage.[59] The soft high leaded bronzes also have good embeddability[60] properties, allowing them to trap foreign particles and contaminants, preventing consequential surface damage.

Alloys of copper, aluminium and iron in a solid solution (aluminium bronzes) produce a hard, high strength and corrosion resistant bearing material with good impact resistance and load carrying properties. Being considerably harder than the leaded bronzes, these alloys require better alignments and more reliable lubrication to minimise local heat generation in the event that the journal contacts the shaft.[61] Abrasives that find their way into the bearing are also a problem for the harder bearing materials, as the alloys are less able to embed the contaminants.

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[59] New design method for boundary lubricated sleeve bearings', W.A. Glaeser, K.F. Dufrane, Machine design, April 1978.

[60] Emeddability is the ability of the bearing lining material to absorb or embed within itself any of the larger of the small dirt particles present in the lubrication system. *Machinery's Handbook*,27th Edition, Industrial Press, page 2260.

[61] *Machinery's Handbook*, 27th Edition, Industrial Press, page. 2225

2 ANALYSIS

2.1 Pump failure

Examination of the engine-driven fuel pump from the right engine of ANV found that the drive pin had failed in torsional shear overload, disconnecting the pump from the accessory gear drive. The torsional shear overload of the drive pin resulted from partial seizure between the pump shaft and the sleeve bearing and was attributed to galling damage to the sleeve bearing and spindle shaft surfaces.

The sleeve bearing was replaced during the last local overhaul of the pump. The replacement sleeve had been manufactured from aluminium bronze, an alloy dissimilar to the high leaded bronze used for the bearing sleeve in other identical pumps produced by the same manufacturer.

Aluminium bronze is recognised in engineering literature as having inferior galling resistance and embeddability properties when compared to the high leaded bronze sleeve bearing material. Galling resistance is a desirable property in a bearing alloy during start up and other marginal lubrication conditions where surface to surface contact can be expected. Similarly, the ability of a bearing alloy to embed foreign abrasive materials is also important to reduce consequential surface scoring damage, particularly if the ingress of those contaminants is possible during the life of the component.

It was not possible to identify the specific factors that initiated the galling damage to the bearing surface and spindle shaft in question. However, the manufacture of the replacement bearing sleeve from a material with inferior galling resistance and embeddability characteristics was significant when considering the damage exhibited by the bearing sleeve, the consequent partial seizure of the spindle shaft and the torsional shear overload of the pump drive pin. The discolouration and thermally induced cracking of the spindle shaft attested to the high friction levels being developed within the galled areas. Heating of the extent sustained is associated with high spindle speeds and confirmed that the galling and pump failure occurred during engine operation.

The failed pump drive pin was of a similar physical construction and material hardness to other pins examined and hence a mechanical strength inadequacy was discounted as having contributed to the torsional shear overload failure.

2.2 Engineering order

Engineering order 6826-1 specified the use of an aluminium bronze alloy for the replacement of the sleeve bearing for the right engine-driven fuel pump. In view of the design application and the subsequent failure mechanism, that specification was considered erroneous and suggests that prior knowledge of the original bearing material specification was unavailable, nor was it obtained by positive analytical identification of the original bearing or an exemplar item.

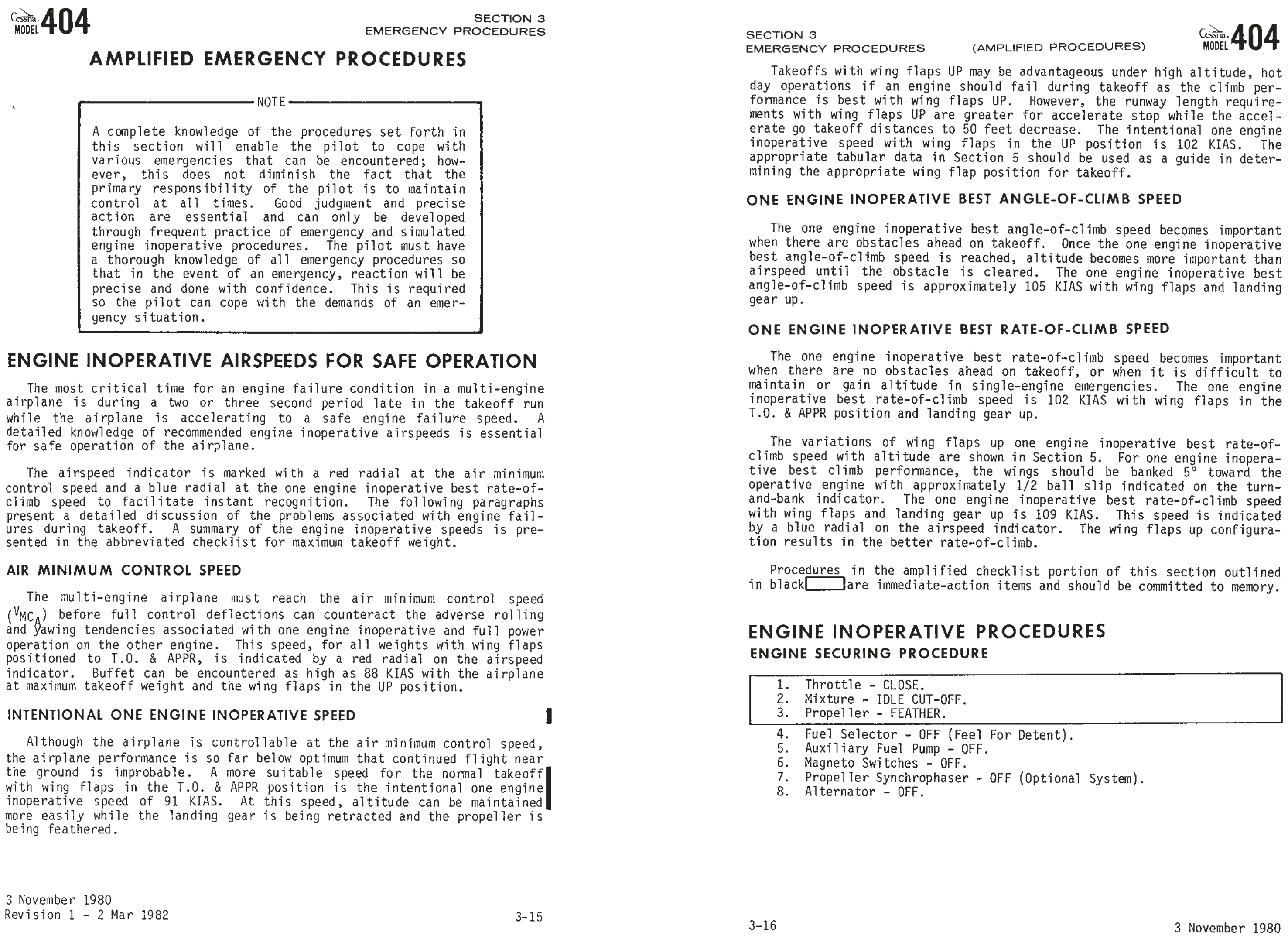
3 CONCLUSIONS

3.1 Significant factors

Examination and analysis of the engine-driven fuel pumps identified the following factors significant to the failure of the drive pin of the right pump.

1. The sleeve bearing of the right EDFP was replaced during the last local overhaul in accordance with a one-off engineering order. That engineering order specified the use of an aluminium bronze alloy for the manufacture of the replacement sleeve bearing.
2. The process of producing the engineering order did not positively identify the original sleeve bearing material.
3. The material selected for the manufacture of the replacement sleeve bearing (aluminium bronze) did not possess the degree of galling resistance and hard particle embeddability of the high leaded bronze alloys.
4. Under operational conditions, the inferior bearing properties of the aluminium bronze sleeve bearing contributed to the development of localised surface adhesive wear (galling) between the spindle shaft and sleeve.
5. Increased friction from the galling resulted in a partial seizure of the pump shaft and the torsional overload failure of the pump drive pin, with the immediate loss of drive to the pump.

APPENDIX B: Extract from Aircraft Manufacturer's AFM



Cessna MODEL 404

SECTION 3
EMERGENCY PROCEDURES

AMPLIFIED EMERGENCY PROCEDURES

NOTE

A complete knowledge of the procedures set forth in this section will enable the pilot to cope with various emergencies that can be encountered; however, this does not diminish the fact that the primary responsibility of the pilot is to maintain control at all times. Good judgment and precise action are essential and can only be developed through frequent practice of emergency and simulated engine inoperative procedures. The pilot must have a thorough knowledge of all emergency procedures so that in the event of an emergency, reaction will be precise and done with confidence. This is required so the pilot can cope with the demands of an emergency situation.

ENGINE INOPERATIVE AIRSPEEDS FOR SAFE OPERATION

The most critical time for an engine failure condition in a multi-engine airplane is during a two or three second period late in the takeoff run while the airplane is accelerating to a safe engine failure speed. A detailed knowledge of recommended engine inoperative airspeeds is essential for safe operation of the airplane.

The airspeed indicator is marked with a red radial at the air minimum control speed and a blue radial at the one engine inoperative best rate-of-climb speed to facilitate instant recognition. The following paragraphs present a detailed discussion of the problems associated with engine failures during takeoff. A summary of the engine inoperative speeds is presented in the abbreviated checklist for maximum takeoff weight.

AIR MINIMUM CONTROL SPEED

The multi-engine airplane must reach the air minimum control speed (V_{MCA}) before full control deflections can counteract the adverse rolling and yawing tendencies associated with one engine inoperative and full power operation on the other engine. This speed, for all weights with wing flaps positioned to T.O. & APPR, is indicated by a red radial on the airspeed indicator. Buffet can be encountered as high as 88 KIAS with the airplane at maximum takeoff weight and the wing flaps in the UP position.

INTENTIONAL ONE ENGINE INOPERATIVE SPEED

Although the airplane is controllable at the air minimum control speed, the airplane performance is so far below optimum that continued flight near the ground is improbable. A more suitable speed for the normal takeoff with wing flaps in the T.O. & APPR position is the intentional one engine inoperative speed of 91 KIAS. At this speed, altitude can be maintained more easily while the landing gear is being retracted and the propeller is being feathered.

3 November 1980
Revision 1 - 2 Mar 1982

3-15

SECTION 3
EMERGENCY PROCEDURES (AMPLIFIED PROCEDURES)

Cessna MODEL 404

Takeoffs with wing flaps UP may be advantageous under high altitude, hot day operations if an engine should fail during takeoff as the climb performance is best with wing flaps UP. However, the runway length requirements with wing flaps UP are greater for accelerate stop while the accelerate go takeoff distances to 50 feet decrease. The intentional one engine inoperative speed with wing flaps in the UP position is 102 KIAS. The appropriate tabular data in Section 5 should be used as a guide in determining the appropriate wing flap position for takeoff.

ONE ENGINE INOPERATIVE BEST ANGLE-OF-CLIMB SPEED

The one engine inoperative best angle-of-climb speed becomes important when there are obstacles ahead on takeoff. Once the one engine inoperative best angle-of-climb speed is reached, altitude becomes more important than airspeed until the obstacle is cleared. The one engine inoperative best angle-of-climb speed is approximately 105 KIAS with wing flaps and landing gear up.

ONE ENGINE INOPERATIVE BEST RATE-OF-CLIMB SPEED

The one engine inoperative best rate-of-climb speed becomes important when there are no obstacles ahead on takeoff, or when it is difficult to maintain or gain altitude in single-engine emergencies. The one engine inoperative best rate-of-climb speed is 102 KIAS with wing flaps in the T.O. & APPR position and landing gear up.

The variations of wing flaps up one engine inoperative best rate-of-climb speed with altitude are shown in Section 5. For one engine inoperative best climb performance, the wings should be banked 5° toward the operative engine with approximately 1/2 ball slip indicated on the turn-and-bank indicator. The one engine inoperative best rate-of-climb speed with wing flaps and landing gear up is 109 KIAS. This speed is indicated by a blue radial on the airspeed indicator. The wing flaps up configuration results in the better rate-of-climb.

Procedures in the amplified checklist portion of this section outlined in black ☐ are immediate-action items and should be committed to memory.

ENGINE INOPERATIVE PROCEDURES

ENGINE SECURING PROCEDURE

1. Throttle - CLOSE.
2. Mixture - IDLE CUT-OFF.
3. Propeller - FEATHER.
4. Fuel Selector - OFF (Feel For Detent).
5. Auxiliary Fuel Pump - OFF.
6. Magneto Switches - OFF.
7. Propeller Synchrophaser - OFF (Optional System).
8. Alternator - OFF.

3-16

3 November 1980

ENGINE FAILURE DURING TAKEOFF (Speed Below 91 KIAS Or Gear Down)

1. Throttles - CLOSE IMMEDIATELY.
2. Brake Or Land and Brake - AS REQUIRED.

NOTE

The distance required for the airplane to be accelerated from a standing start to 91 KIAS on the ground, and to decelerate to a stop with heavy braking, is presented in the Accelerate Stop Distance Chart in Section 5 for various combinations of conditions.

ENGINE FAILURE AFTER TAKEOFF (Speed Above 91 KIAS With Gear Up Or In Transit)

1. Mixtures - FULL RICH.
2. Propellers - FULL FORWARD.
3. Throttles - FULL FORWARD (40.0 Inches Hg.).
4. Landing Gear - CHECK UP.
5. Inoperative Engine:
   a. Throttle - CLOSE.
   b. Mixture - IDLE CUT-OFF.
   c. Propeller - FEATHER.
6. Establish Bank - 5° toward operative engine.
7. *Climb to Clear 50-Foot Obstacle* - 91 KIAS (*Wing Flaps T.O. & APPR*).
   - 102 KIAS (*Wing Flaps UP*).
8. *Climb at One Engine Inoperative Best Rate-of-Climb Speed (Wing Flaps In T.O. & APPR Position)* - 102 KIAS.
9. *Wing Flaps* - UP (*If Extended*).
10. Climb at Best Single-Engine Rate-of-Climb Speed (Wing Flaps UP) - 109 KIAS.
11. Trim Tabs - ADJUST 5° bank toward operative engine with approximately 1/2 ball slip *indicated on the turn and bank* indicator.
12. Inoperative Engine - SECURE as follows:
    a. Fuel Selector - OFF (Feel For Detent).
    b. Auxiliary Fuel Pump - OFF.
    c. Magneto Switches - OFF.
    d. Alternator Switch - OFF.
13. As Soon as Practical - LAND.

Upon engine failure after reaching the intentional one engine inoperative speed on takeoff, the multi-engine pilot has a significant advantage over a single-engine pilot, for he has a choice of stopping or continuing the takeoff. This would be similar to the choice facing a single-engine pilot who has suddenly lost slightly more than half of his takeoff power. In this situation, the single-engine pilot would be extremely reluctant to continue the takeoff if he had to climb over obstructions. However, if the failure occurred at an altitude as high or higher than surrounding obstructions, *he would feel free to maneuver for a landing back at the airport.*

GO NO-GO DECISION
ENGINE FAILURE DURING TAKEOFF

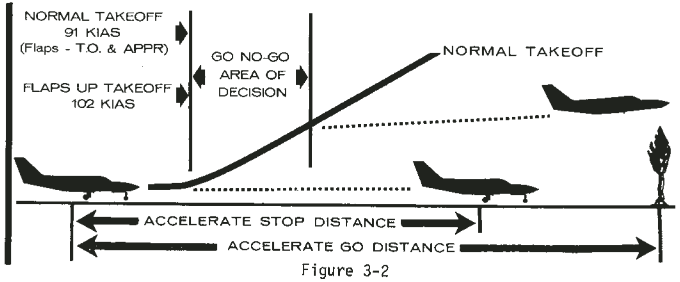


Figure 3-2

Fortunately, the airplane accelerates through this "area of decision" in just a few seconds. However, to make an intelligent decision in this type of emergency, one must consider the field length, obstruction height, field elevation, air temperature, headwind, and takeoff weight. The flight paths illustrated in Figure 3-2 indicate that the "go no-go area of decision" is bounded by: (1) the point at which the intentional one engine inoperative speed is reached and (2) the point where the obstruction altitude is reached. An engine failure in this area requires an immediate decision. Beyond this area, the airplane, within the limitations of single-engine climb performance shown in Section 5, may be maneuvered to a landing back at the airport.

At sea level standard day, with zero wind, wing flaps positioned to T.O. & APPR and 8400 pounds weight, the distance to accelerate to 91 KIAS and stop is 3460 feet, while the total unobstructed distance required to takeoff and climb over a 50-foot obstacle after an engine failure at 91 KIAS is 4698 feet. This total distance over an obstacle can be reduced slightly under more favorable conditions of weight, headwind, or obstruction height. However, it is recommended that in most cases it would be better to discontinue the takeoff, since any slight mismanagement of single-engine procedure would more than offset the small distance advantage offered by continuing the takeoff. Still higher field elevations will cause the engine failure takeoff distance to lengthen disproportionately until the altitude is reached where a successful takeoff is improbable unless the airspeed and height above the runway at engine failure are great enough to allow a slight deceleration and altitude loss while the airplane is being prepared for an engine inoperative climb.

During engine inoperative takeoff procedures over an obstacle, only one condition presents any appreciable advantage; this is headwind. A decrease of approximately 6% in ground distance required to clear a 50-foot obstacle can be gained for each 10 knots of headwind. Excessive speed above one engine inoperative best rate-of-climb speed at engine failure is not nearly as advantageous as one might expect since deceleration is rapid and ground distance is used up quickly at higher speeds while the airplane is being cleaned up for climb. However, the extra speed is important for controllability.

The following facts should be used as a guide at the time of engine failure during takeoff: (1) discontinuing a takeoff upon engine failure is advisable under most circumstances; (2) altitude is more valuable to safety after takeoff than is airspeed in excess of the one engine inoperative best rate-of-climb speed since excess airspeed is lost much more rapidly than is altitude; (3) climb or continued level flight at moderate altitude is improbable with the landing gear extended and the propeller windmilling; (4) in no case should the airspeed be allowed to fall below the intentional one engine inoperative speed, even though altitude is lost, since this speed will always provide a better chance of climb, or a smaller altitude loss, than any lesser speed; and (5) if the requirement for an immediate climb is not present, allow the airplane to accelerate to the one engine inoperative best rate-of-climb speed as this is the optimum climb speed and will always provide the best chance of climb or least altitude loss.

WARNING

The propeller on the inoperative engine must be feathered, landing gear retracted and wing flaps up or continued flight may be impossible.

ENGINE OVERSPEED

Should an overspeed condition occur, the pilot should reduce airspeed as quickly as possible by closing both throttles. On reaching an airspeed below 120 KIAS and above the one engine inoperative best rate-of-climb speed (Blue Radial), set the propeller control on the overspeeding engine for feather. If propeller will not feather, the power on the normally operating engine should be advanced to maximum and the power on the overspeeding engine should be advanced to 50 RPM below the maximum allowable RPM (Red Line). Maintain the one engine inoperative best rate-of-climb speed (Blue Radial) and land as soon as practical. This will provide more than zero thrust at altitudes up to approximately 10,000 feet. During landing, the application of partial throttle on the malfunctioning engine (within limits of the tachometer red line) will minimize asymmetrical thrust.

SUDDEN ENGINE ROUGHNESS

1. Power - REDUCE IMMEDIATELY (Both Engines).
   a. Manifold Pressure - 33.5 inches Hg. maximum.
   b. RPM - (1800 Maximum).
2. Propeller Synchrophaser - OFF (Optional System).
3. Rough Engine - DETERMINE.
4. Problem - ANALYZE.
5. Rough Engine - SECURE if roughness cannot be cleared.
6. Operative Engine - ADJUST.
7. Trim Tabs - ADJUST 5° bank toward operative engine with approximately 1/2 ball skid indicated on the turn and bank indicator.
8. As Soon As Practical - LAND.

If the ignition system produces an engine speed drop in excess of 100 RPM, or if the drop in RPM between the left and right magneto differs by more than 50 RPM, continue warm-up a minute or two longer before rechecking the system. If there is doubt concerning operation of the ignition system, checks at higher engine speed will usually confirm if a deficiency exists. In general, a drop in excess of 100 RPM is not considered acceptable. Magneto checks should not be made in the yellow arc. The most effective RPM range for detecting magneto roughness is between 1100 and 1500 RPM.

A careful check should be made of the vacuum system. The minimum and maximum allowable suctions are 4.75 and 5.25 inches Hg., respectively, on the instrument. Good alternator condition is also important for instrument flight since satisfactory operation of all avionics equipment and electrical instruments is essential. The alternators are checked during engine runup (1500 RPM) by positioning the selector switch in the L ALT and R ALT position and observing the charging rate on the voltammeter.

A simple last minute recheck of important items should include a quick glance to see if all switches are ON, the mixture and propeller controls are forward, all flight controls have free and correct movement and the fuel selectors are properly positioned.

NOTE

Make sure that weight does not exceed 8400 pounds before attempting takeoff.

A mental review of all single-engine speeds, procedures and field length requirements should be made prior to takeoff.

TAKEOFF

1. Power - 2235 RPM and FULL THROTTLE.

NOTE

Apply full throttle smoothly to avoid propeller surging and excessive manifold pressures. Refer to Section 7 if momentary overboost of manifold pressure occurs.

2. Mixtures - CHECK fuel flows in the white arc.
3. Engine Instruments - CHECK.
4. Takeoff and
   Climb to 50 Feet - 91 KIAS at 8400 pounds and wing flaps in T.O. & APPR position. Refer to Section 5 for speeds at reduced weights.
   - 102 KIAS at 8400 pounds and wing flaps in UP position. Refer to Section 5 for speeds at reduced weights.

Before initiating the takeoff roll, a go, no-go decision should have been made in the event an engine failure should occur. Review the anticipated performance presented in the Accelerate-Stop Distance, Accelerate-Go Distance and Engine Inoperative Rate-of-Climb charts in Section 5. In addition, review the applicable procedures and speeds associated with single-engine operation so that the transition (in the event of an engine failure) will be smooth, positive and safe. If the anticipated performance exceeds the runway length available or obstacle clearance requirements cannot be achieved, it is recommended to takeoff on a more favorable runway, off-load the airplane until the anticipated performance is consistent with existing conditions or delay the takeoff until more favorable atmospheric conditions exist.

Since the use of full throttle is not recommended in the static runup, closely observe full-power engine operation early in the takeoff run. The maximum allowable manifold pressure of 40.0 inches Hg. manifold pressure should not be exceeded. Throttle action should be smooth and slow in order that the waste gate can become operative as early as possible. Signs of rough engine operation, unequal power between engines, or sluggish engine acceleration are good cause for discontinuing the takeoff. If this occurs, make a thorough full throttle static runup before another takeoff is attempted.

Full throttle operation is recommended on takeoff since it is important that a speed well above air minimum control or buffet speed be obtained as rapidly as possible. It is desirable to accelerate the airplane to the recommended safe single-engine speed (91 KIAS with wing flaps positioned to the normal T.O. & APPR or 102 KIAS with wing flaps positioned to UP) before lift-off for additional safety in case of an engine failure.

Takeoffs are normally accomplished with wing flaps positioned to T.O. & APPR as this flap position provides the shortest possible distance, with all engines operating, to clear a 50-foot obstacle. The use of T.O. & APPR wing flaps allows lower takeoff speeds as compared to takeoffs with wing flaps positioned to UP. Takeoffs with wing flaps UP may be advantageous under high altitude, hot day operations if an engine should fail during takeoff as the climb performance is best with wing flaps UP. However, the runway length requirements with wing flaps UP are greater for accelerate stop and all engines takeoff to 50 feet. If a takeoff is to be attempted where obstacle clearance is of prime consideration, a review of the tabular data in Section 5 should be used as a guide in determining the appropriate wing flap position for takeoff.

For crosswind takeoffs, additional power may be carried on the upwind engine until the rudder becomes effective. The airplane is accelerated to a slightly higher than normal takeoff speed, and then is pulled off abruptly to prevent possible settling back to the runway while drifting. When clear of the ground, a coordinated turn is made into the wind to correct for drift.

A takeoff with one main tank full and the opposite tank low on fuel creates a lateral unbalance. This is not recommended since gusty air or premature lift-off could create a serious control problem.

After takeoff, it is important to maintain the intentional one engine inoperative climb speed to 50 feet. As the airplane accelerates still further to all engines best rate-of-climb speed, it is good practice to climb rapidly to an altitude at which the airplane is capable of circling the field on one engine.

AFTER TAKEOFF

1. Brakes - APPLY momentarily.
2. Landing Gear - RETRACT. Check gear unlocked and HYD PRESS lights off.
3. Best Angle-of-Climb Speed (Sea Level With Wing Flaps Positioned To T.O. & APPR) - 82 KIAS after reaching 50 feet if immediate obstacle clearance is a consideration.
4. Best Rate-of-Climb Speed With Wing Flaps In T.O. & APPR Position - 102 KIAS at sea level and 8400 pounds. Refer to Section 5 for climb speed at altitude and reduced weight.
5. Wing Flaps - UP (If Extended).
6. Best Angle-of-Climb Speed With Wing Flaps UP - 96 KIAS if long range obstacle clearance is a consideration. Refer to following text for climb speed at altitude.
7. Best Rate-of-Climb Speed With Wing Flaps UP - 108 KIAS at sea level and 8400 pounds. Refer to Section 5 for climb speed at altitude and reduced weight.
8. Auxiliary Fuel Pumps - CHECK ON.

To establish climb configuration, retract the landing gear and wing flaps, set climb power, check auxiliary fuel pumps on and adjust the mixtures for the selected power setting.

Before retracting the landing gear, apply the brakes momentarily to stop the rotation of the main wheels. Centrifugal force caused by the rapidly rotating wheels expands the diameter of the tires, and if ice or mud has accumulated in the wheel wells, the rotating wheels may rub as they enter.

On long runways, the landing gear should be retracted at the point over the runway where a wheels-down forced landing on that runway would become impractical. However, on short runways it may be preferable to retract the landing gear after the airplane is safely airborne.

Power reduction will vary according to the requirements of the traffic pattern or surrounding terrain, weight, field elevation, temperature, environmental considerations and engine condition. However, a normal after takeoff power setting is 1900 RPM and 33.5 inches Hg. manifold pressure. In any case, avoid continuous operation in the yellow arc (1900 to 2185 RPM).

ACCELERATE STOP DISTANCE

NORMAL TAKEOFF WING FLAPS - T.O. & APPR

CONDITIONS:

1. 2235 RPM and 40.0 Inches Hg. Manifold Pressure Before Brake Release.
2. Mixtures - CHECK Fuel Flows In The White Arc.
3. Wing Flaps - T.O. & APPR.
4. Level, Hard Surface, Dry Runway.
5. Engine Failure at Engine Failure Speed.
6. Idle Power and Maximum Effective Braking After Engine Failure.

NOTE:

1. If full power is applied without brakes set, distances apply from point where full power is applied.
2. Decrease distance 3% for each 4 knots headwind.
3. Increase distance 5% for each 2 knots tailwind.
4. Shaded area indicates deceleration rates are unpredictable unless heavy-duty brakes are installed.
5. Accelerate stop distances for a given set of conditions are always shorter with wing flaps positioned to T.O. & APPR.

WEIGHT - POUNDS	ENGINE FAILURE SPEED - KIAS	PRESSURE ALTITUDE - FEET	TOTAL DISTANCE - FEET						
			-20°C -4°F	-10°C +14°F	0°C 32°F	+10°C +50°F	+20°C +68°F	+30°C +86°F	+40°C +104°F
8400	91	Sea Level	2810	2980	3170	3360	3570	3790	4080
		1000	2940	3130	3330	3530	3750	4040	4290
		2000	3090	3290	3490	3760	4000	4250	4510
		3000	3240	3450	3720	3960	4200	4470	4750
		4000	3410	3680	3910	4160	4420	4710	5000
		5000	3580	3870	4120	4380	4660	4960	5280
		6000	3820	4070	4340	4620	4910	5230	5570
		7000	4020	4290	4570	4870	5190	5530	5890
		8000	4240	4520	4820	5140	5480	5840	6230
		9000	4470	4770	5090	5430	5790	6180	6600
		10,000	4720	5040	5380	5740	6130	6550	7000
7700	86	Sea Level	2300	2440	2590	2750	2910	3090	3280
		1000	2410	2560	2720	2890	3060	3250	3440
		2000	2530	2690	2860	3030	3220	3410	3680
		3000	2660	2820	3000	3190	3380	3640	3870
		4000	2790	2970	3160	3350	3610	3840	4070
		5000	2930	3120	3320	3580	3800	4040	4290
		6000	3090	3290	3540	3770	4010	4260	4530
		7000	3250	3510	3730	3970	4230	4500	4780
		8000	3470	3700	3940	4190	4460	4750	5060
		9000	3660	3900	4150	4430	4710	5020	5350
		10,000	3860	4120	4390	4680	4990	5320	5670
7000	82	Sea Level	1850	1970	2080	2210	2340	2470	2620
		1000	1940	2060	2190	2320	2450	2600	2750
		2000	2040	2160	2290	2430	2580	2730	2900
		3000	2140	2270	2410	2560	2710	2870	3050
		4000	2240	2390	2530	2690	2850	3030	3210
		5000	2360	2510	2660	2830	3000	3190	3430
		6000	2480	2640	2810	2980	3210	3410	3620
		7000	2610	2780	2960	3180	3380	3590	3820
		8000	2750	2930	3160	3360	3570	3790	4030
		9000	2900	3130	3330	3540	3770	4010	4260
		10,000	3100	3300	3520	3740	3980	4240	4510
6300	78	Sea Level	1460	1550	1640	1730	1830	1940	2050
		1000	1530	1620	1720	1820	1920	2040	2150
		2000	1600	1700	1800	1910	2020	2140	2260
		3000	1680	1780	1890	2010	2120	2250	2380
		4000	1770	1870	1990	2110	2230	2370	2510
		5000	1860	1970	2090	2220	2350	2490	2640
		6000	1950	2070	2200	2340	2480	2630	2780
		7000	2050	2180	2320	2460	2610	2770	2940
		8000	2160	2300	2450	2600	2760	2960	3140
		9000	2280	2430	2580	2740	2950	3130	3320
		10,000	2410	2560	2730	2930	3110	3310	3510

Figure 5-12

ACCELERATE GO DISTANCE

NORMAL TAKEOFF WING FLAPS - T.O. & APPR

CONDITIONS:

1. 2235 RPM and 40.0 Inches Hg. Manifold Pressure Before Brake Release.
2. Mixtures - CHECK Fuel Flows In The White Arc.
3. Wing Flaps - T.O. & APPR.
4. Level, Hard Surface, Dry Runway.
5. Engine Failure At Engine Failure Speed.
6. Landing Gear Up Or In Transit And Propeller Feathered During Climb.
7. Maintain Engine Failure Speed Until Clear of Obstacle.

NOTE:

1. If full power is applied without brakes set, distances apply from point where full power is applied.
2. Decrease distance 6% for each 10 knots headwind.
3. Increase distance 5% for each 2 knots tailwind.
4. Distances in boxes represent rates of climb less than 50 ft/min.
5. When takeoff performance is in the shaded area and obstacle clearance is a consideration, recommend takeoff with wing flaps positioned to UP.

WEIGHT - POUNDS	ENGINE FAILURE SPEED - KIAS	PRESSURE ALTITUDE FEET	TOTAL DISTANCE TO CLEAR 50-FOOT OBSTACLE - FEET						
			-20°C -4°F	-10°C +14°F	0°C 32°F	+10°C +50°F	+20°C +68°F	+30°C +86°F	+40°C +104°F
8400	91	Sea Level	2800	3170	3640	4280	5230	6880	10,820
		1000	2990	3400	3950	4710	5910	8280	15,440
		2000	3200	3680	4310	5290	6870	10,420	------
		3000	3440	3990	4790	5960	8160	14,490	------
		4000	3720	4400	5320	6850	10,180	------	------
		5000	4040	4840	5990	8110	13,920	------	------
		6000	4460	5380	6880	10,070	------	------	------
		7000	4910	6060	8140	13,680	------	------	------
		8000	5460	6970	10,110	------	------	------	------
		9000	6160	8260	13,750	------	------	------	------
		10,000	7110	10,300	------	------	------	------	------
7700	86	Sea Level	2080	2300	2560	2860	3240	3730	4410
		1000	2210	2440	2720	3060	3490	4060	4870
		2000	2340	2600	2910	3290	3780	4440	5500
		3000	2490	2770	3110	3540	4100	4950	6240
		4000	2650	2960	3340	3830	4540	5530	7240
		5000	2820	3170	3610	4220	5010	6260	8700
		6000	3020	3410	3950	4620	5590	7260	11,110
		7000	3240	3730	4300	5100	6340	8710	16,010
		8000	3540	4040	4720	5700	7360	11,090	------
		9000	3820	4410	5220	6480	8840	15,950	------
		10,000	4150	4850	5860	7540	11,320	------	------
7000	82	Sea Level	1620	1770	1940	2130	2360	2630	2960
		1000	1710	1870	2050	2260	2510	2810	3180
		2000	1800	1980	2170	2400	2680	3010	3430
		3000	1900	2090	2310	2560	2860	3230	3710
		4000	2020	2220	2460	2730	3070	3490	4040
		5000	2140	2360	2620	2920	3300	3780	4490
		6000	2270	2520	2800	3140	3610	4170	4960
		7000	2420	2690	3000	3430	3920	4580	5560
		8000	2580	2880	3270	3700	4270	5070	6340
		9000	2760	3130	3520	4030	4700	5700	7410
		10,000	3000	3370	3820	4410	5230	6510	9040
6300	78	Sea Level	1240	1340	1460	1590	1730	1890	2080
		1000	1300	1410	1540	1670	1830	2000	2200
		2000	1370	1490	1620	1770	1930	2120	2340
		3000	1440	1570	1710	1870	2050	2250	2500
		4000	1520	1660	1810	1980	2170	2400	2670
		5000	1610	1750	1920	2100	2310	2560	2850
		6000	1700	1860	2040	2230	2470	2740	3060
		7000	1800	1970	2160	2380	2630	2940	3340
		8000	1910	2100	2300	2540	2820	3200	3620
		9000	2030	2230	2460	2720	3070	3450	3930
		10,000	2170	2390	2640	2960	3310	3740	4300

Figure 5-13

ACCELERATE STOP DISTANCE

FLAPS UP TAKEOFF

CONDITIONS:

1. 2235 RPM and 40.0 Inches Hg. Manifold Pressure Before Brake Release.
2. Mixtures - CHECK Fuel Flows In The White Arc.
3. Wing Flaps - UP.
4. Level, Hard Surface, Dry Runway.
5. Engine Failure at Engine Failure Speed.
6. Idle Power and Maximum Effective Braking After Engine Failure.

NOTE:

1. If full power is applied without brakes set, distances apply from point where full power is applied.
2. Decrease distance 2% for each 3 knots headwind.
3. Increase distance 5% for each 2 knots tailwind.
4. Shaded area indicates deceleration rates are unpredictable unless heavy-duty brakes are installed.
5. ---- line indicates deceleration rates are unpredictable due to possible brake fading with either standard or heavy-duty brakes.
6. Accelerate stop distances for a given set of conditions are always shorter with wing flaps positioned to T.O. & APPR.

WEIGHT - POUNDS	ENGINE FAILURE SPEED - KIAS	PRESSURE ALTITUDE - FEET	TOTAL DISTANCE - FEET						
			-20°C -4°F	-10°C +14°F	0°C 32°F	+10°C +50°F	+20°C +68°F	+30°C +86°F	+40°C +104°F
8400	102	Sea Level	3470	3680	3910	4150	4410	4680	4970
		1000	3630	3860	4100	4360	4630	4920	5220
		2000	3810	4050	4310	4580	4860	5170	5490
		3000	4000	4250	4530	4810	5120	5440	5780
		4000	4200	4470	4760	5060	5380	5730	6090
		5000	4410	4700	5000	5330	5670	6040	6430
		6000	4640	4940	5270	5610	5980	6370	----
		7000	4880	5210	5550	5920	6300	----	----
		8000	5140	5490	5850	6240	----	----	----
		9000	5420	5790	6180	----	----	----	----
		10,000	5720	6110	----	----	----	----	----
7700	97	Sea Level	2810	2980	3200	3390	3600	3810	4040
		1000	2940	3160	3360	3560	3780	4010	4250
		2000	3120	3320	3520	3740	3970	4210	4470
		3000	3270	3480	3700	3930	4170	4430	4700
		4000	3440	3650	3880	4130	4380	4660	4950
		5000	3610	3840	4080	4340	4620	4910	5220
		6000	3790	4040	4300	4570	4860	5170	5500
		7000	3990	4250	4530	4820	5130	5460	5810
		8000	4200	4480	4770	5080	5410	5760	6140
		9000	4430	4720	5030	5360	5710	6090	6490
		10,000	4670	4980	5320	5670	6040	6440	6870
7000	91	Sea Level	2250	2390	2540	2690	2850	3050	3230
		1000	2360	2510	2660	2820	3030	3200	3390
		2000	2480	2630	2790	3000	3180	3370	3570
		3000	2600	2760	2970	3150	3340	3540	3750
		4000	2730	2930	3120	3310	3510	3720	3950
		5000	2900	3080	3270	3480	3690	3910	4150
		6000	3050	3240	3440	3660	3880	4120	4380
		7000	3200	3410	3620	3850	4090	4350	4620
		8000	3370	3590	3820	4060	4320	4590	4880
		9000	3550	3780	4030	4280	4560	4840	5150
		10,000	3740	3990	4250	4520	4810	5120	5450
6300	84	Sea Level	1770	1880	1990	2110	2230	2360	2490
		1000	1860	1970	2090	2210	2340	2470	2620
		2000	1950	2060	2190	2320	2450	2600	2790
		3000	2040	2170	2300	2430	2580	2770	2930
		4000	2140	2270	2410	2560	2740	2910	3080
		5000	2250	2390	2540	2720	2890	3060	3240
		6000	2360	2510	2700	2860	3040	3220	3410
		7000	2490	2670	2840	3010	3200	3390	3600
		8000	2650	2810	2990	3170	3370	3570	3790
		9000	2790	2960	3150	3350	3550	3770	4010
		10,000	2930	3120	3320	3530	3750	3990	4230

Figure 5-14

ACCELERATE GO DISTANCE

FLAPS UP TAKEOFF

CONDITIONS:

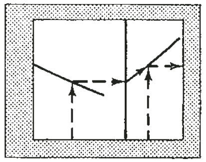
1. 2235 RPM and 40.0 Inches Hg. Manifold Pressure Before Brake Release.
2. Mixtures - CHECK Fuel Flows In The White Arc.
3. Wing Flaps - UP.
4. Level, Hard Surface, Dry Runway.
5. Engine Failure At Engine Failure Speed.
6. Landing Gear Up Or In Transit And Propeller Feathered During Climb.
7. Maintain Engine Failure Speed Until Clear of Obstacle.

NOTE:

1. If full power is applied without brakes set, distances apply from point where full power is applied.
2. Decrease distance 6% for each 10 knots headwind.
3. Increase distance 5% for each 2 knots tailwind.
4. Distance in boxes represent rates of climb less than 50 ft/min.
5. When takeoff performance is in the shaded area and obstacle clearance is a consideration, recommend takeoff with wing flaps positioned to T.O. & APPR.

WEIGHT - POUNDS	ENGINE FAILURE SPEED - KIAS	PRESSURE ALTITUDE FEET	TOTAL DISTANCE TO CLEAR 50-FOOT OBSTACLE - FEET						
			-20°C -4°F	-10°C +14°F	0°C 32°F	+10°C +50°F	+20°C +68°F	+30°C +86°F	+40°C +104°F
8400	102	Sea Level	2990	3320	3720	4220	4880	5810	7310
		1000	3170	3540	3980	4540	5310	6440	8430
		2000	3370	3770	4270	4910	5810	7230	10,030
		3000	3580	4030	4590	5340	6420	8270	$\boxed{12,570}$
		4000	3820	4320	4960	5840	7180	9720	------
		5000	4090	4650	5390	6440	8170	$\boxed{11,940}$	------
		6000	4390	5030	5890	7180	9520	------	------
		7000	4730	5460	6490	8130	$\boxed{11,540}$	------	------
		8000	5110	5960	7220	9420	------	------	------
		9000	5550	6570	8160	$\boxed{11,320}$	------	------	------
		10,000	6070	7310	9430	------	------	------	------
7700	97	Sea Level	2280	2500	2800	3090	3440	3870	4420
		1000	2410	2690	2960	3280	3670	4150	4780
		2000	2580	2840	3140	3500	3920	4460	5190
		3000	2730	3020	3340	3730	4210	4820	5680
		4000	2900	3200	3560	3990	4530	5240	6270
		5000	3070	3410	3800	4280	4890	5720	6990
		6000	3270	3630	4070	4600	5310	6300	7930
		7000	3480	3880	4370	4980	5800	7020	9190
		8000	3710	4160	4700	5400	6380	7920	11,050
		9000	3970	4470	5090	5900	7090	9140	$\boxed{14,160}$
		10,000	4260	4820	5530	6500	8000	10,910	------
7000	91	Sea Level	1800	1960	2140	2340	2570	2880	3200
		1000	1890	2070	2260	2480	2760	3060	3410
		2000	2000	2180	2390	2660	2930	3250	3650
		3000	2110	2300	2560	2820	3120	3470	3910
		4000	2230	2470	2720	2990	3320	3710	4200
		5000	2390	2620	2880	3180	3540	3980	4540
		6000	2530	2780	3060	3400	3790	4280	4920
		7000	2680	2950	3260	3630	4070	4620	5370
		8000	2850	3140	3480	3890	4380	5020	5910
		9000	3030	3350	3730	4180	4740	5480	6560
		10,000	3230	3590	4000	4510	5150	6030	7380
6300	84	Sea Level	1390	1510	1630	1770	1930	2100	2300
		1000	1460	1590	1720	1870	2040	2220	2440
		2000	1540	1670	1810	1970	2150	2350	2620
		3000	1620	1760	1910	2080	2280	2530	2780
		4000	1710	1860	2020	2200	2450	2680	2960
		5000	1800	1960	2140	2370	2590	2850	3150
		6000	1900	2070	2300	2510	2750	3030	3370
		7000	2010	2230	2430	2660	2930	3240	3600
		8000	2160	2360	2580	2830	3120	3460	3870
		9000	2290	2510	2750	3020	3340	3710	4170
		10,000	2430	2670	2930	3220	3570	3990	4510

Figure 5-15



RATE-OF-CLIMB - ONE ENGINE INOPERATIVE

WEIGHT POUNDS	CLIMB SPEED - KIAS	
	Sea Level	16,000 Feet
8400	109	105
7700	102	98
7000	96	91
6300	92	86

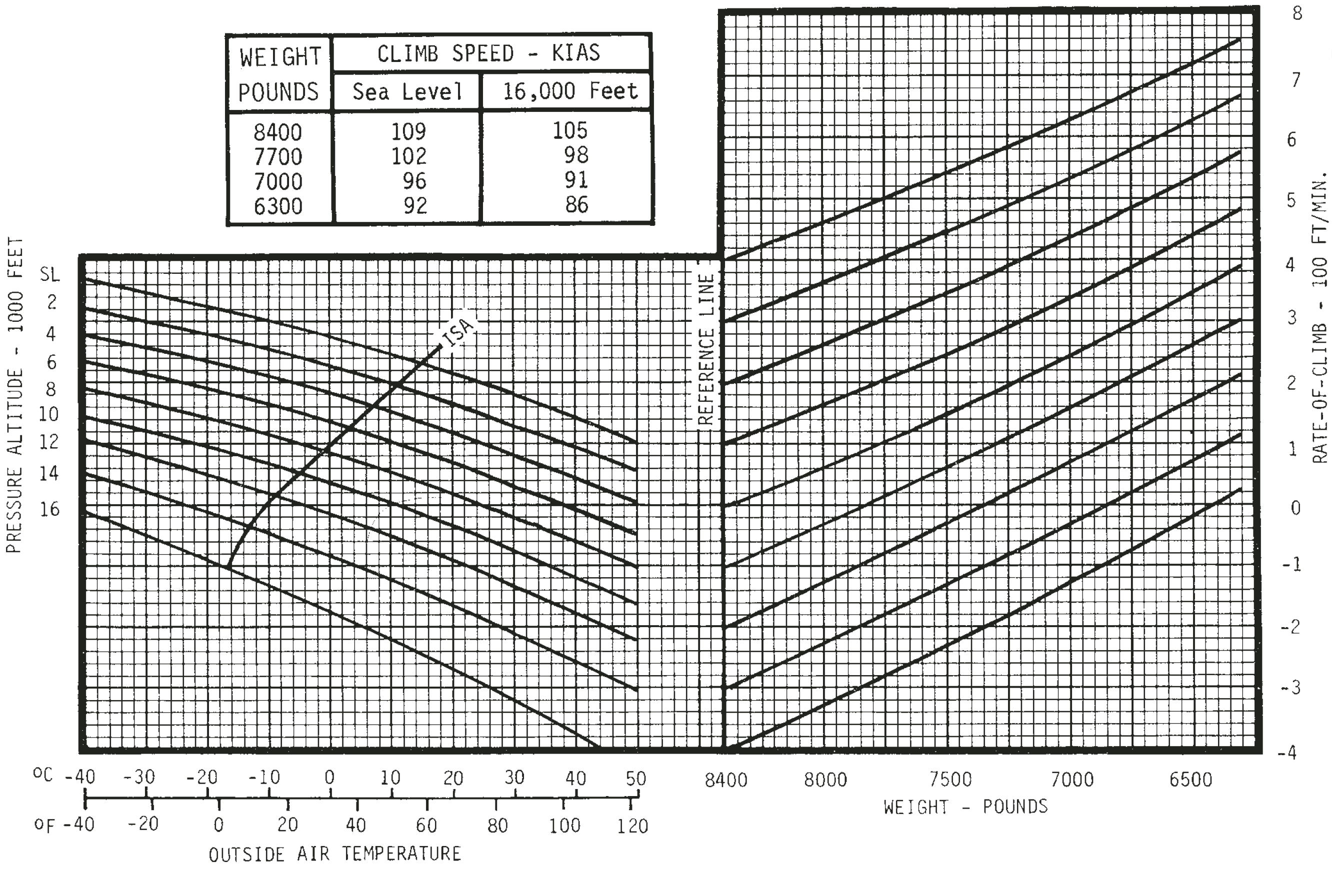


Figure 5-19

CONDITIONS:

1. 2235 RPM and 40.0 Inches Hg. to 16,000 Feet. Use Placarded Manifold Pressure Above 16,000 Feet.
2. Mixture - CHECK Fuel Flow in the White Arc.
3. Landing Gear - UP.
4. Wing Flaps - UP.
5. Inoperative Propeller - FEATHERED.
6. Wings Banked 5° Toward Operative Engine with Approximately 1/2 Ball Slip Indicated on the Turn and Bank Indicator.

NOTE:
Approximate Effect of Configuration on Single Engine Rate-of-Climb.

Subtract values listed below from value obtained in above graph. Effects for a combination of gear, flap or windmilling propeller may be obtained by adding the effects for each.

Inoperative Engine Windmilling	350 Ft/Min
Gear Down	300 Ft/Min
Flaps - T.O. & APPR.	100 Ft/Min
Flaps - LAND	600 Ft/Min

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