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

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1 FACTUAL INFORMATION

1.1 Examination brief

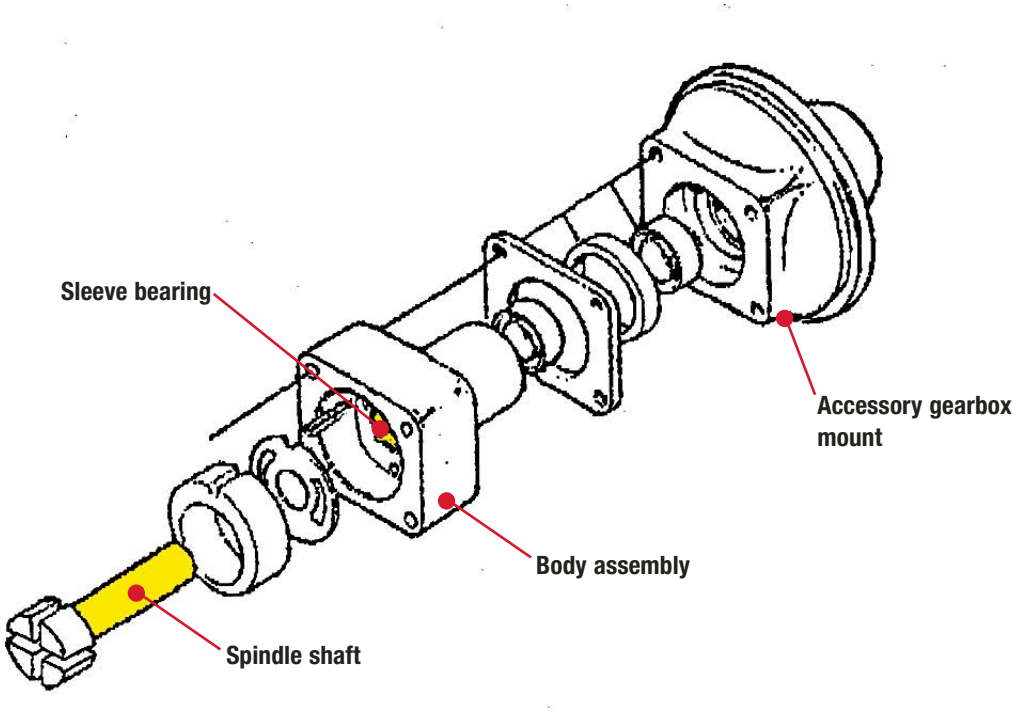
A Cessna Aircraft Company 404 Titan aircraft, registered VH-ANV, impacted terrain shortly after takeoff, during an attempt by the pilot to return and make an emergency landing. Impact forces and an intense post-impact fire destroyed the aircraft. The aircraft engines were amongst various items recovered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

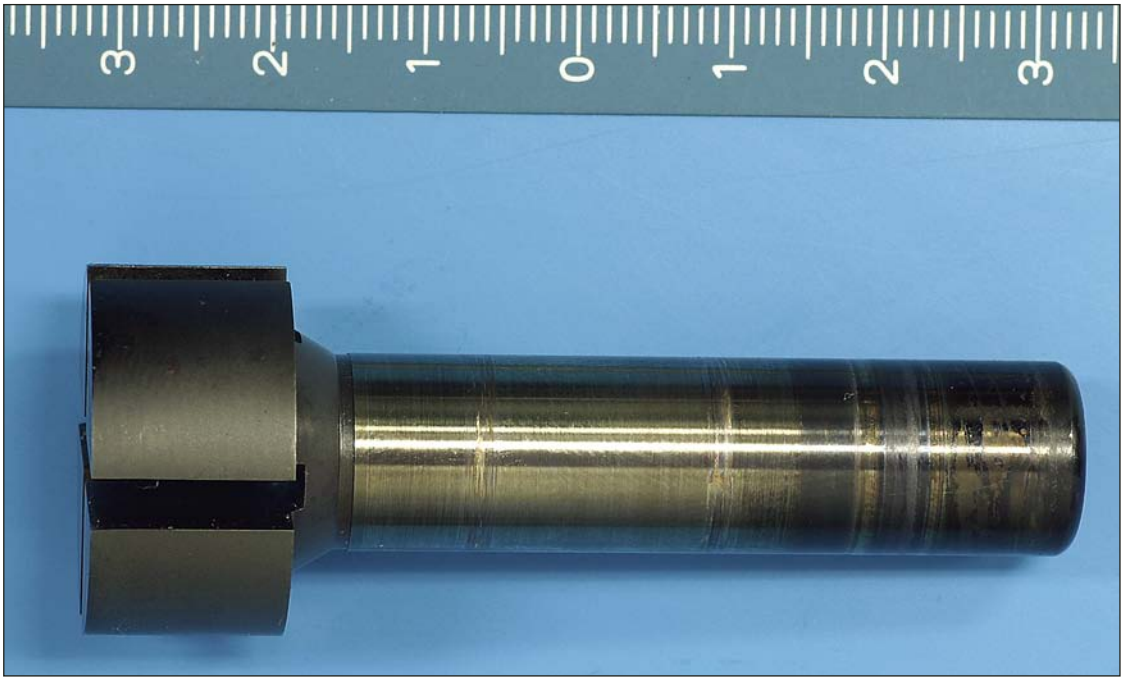
FIGURE 3: Spindle shaft end seal in good condition



Right pump shaft

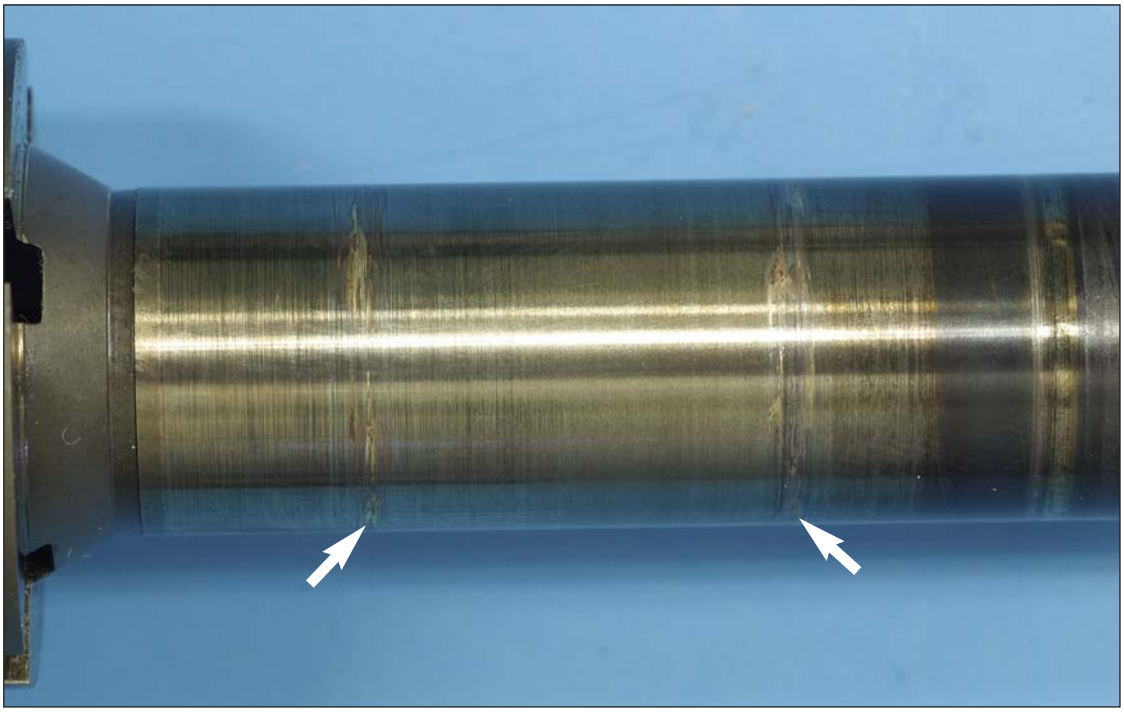
The pump shaft (see Figure 4) exhibited some staining and blackening around the driven end and two circumferential bands of galling[47] and pick-up of metal from the sleeve bearing (see Figure 5). Between those areas, the shaft surfaces appeared sound and undamaged, with no other indications of anomalous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

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



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).

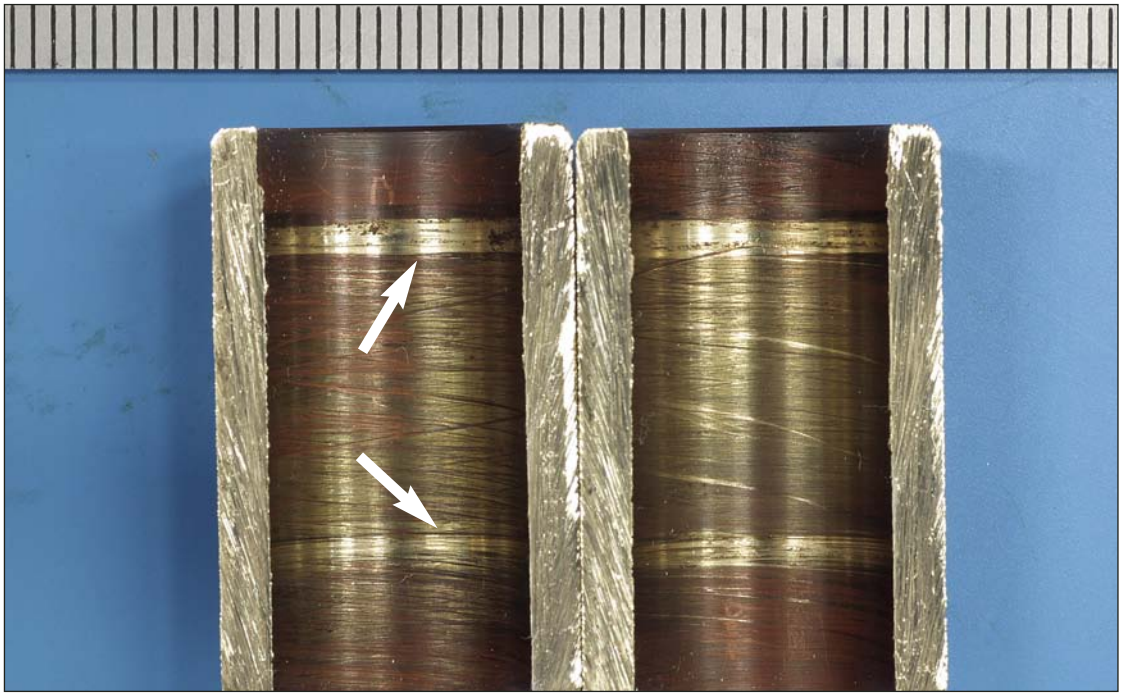
FIGURE 5: Right EDFP spindle shaft, with the two localised areas of galling damage indicated



Sleeve bearing

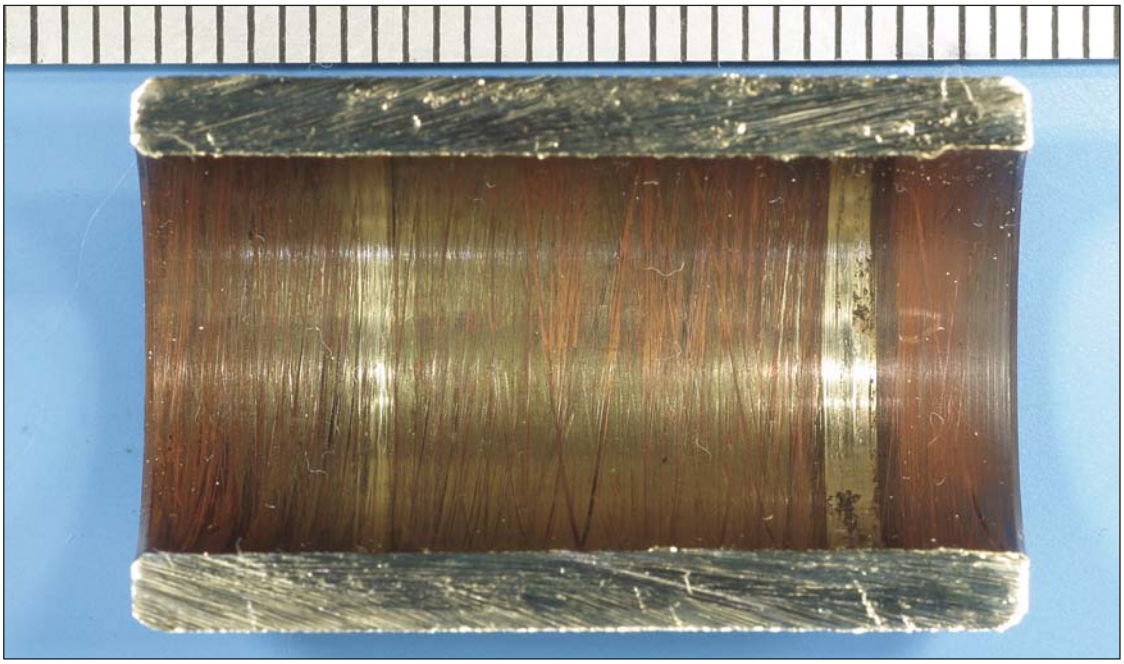
Removal and axial sectioning of the sleeve bearing revealed two bands of galled and polished material that corresponded with the galled areas identified on the surface of the spindle shaft (see Figure 6). Both bands were localised and equidistant from the inner and outer ends of the sleeve bearing. The 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

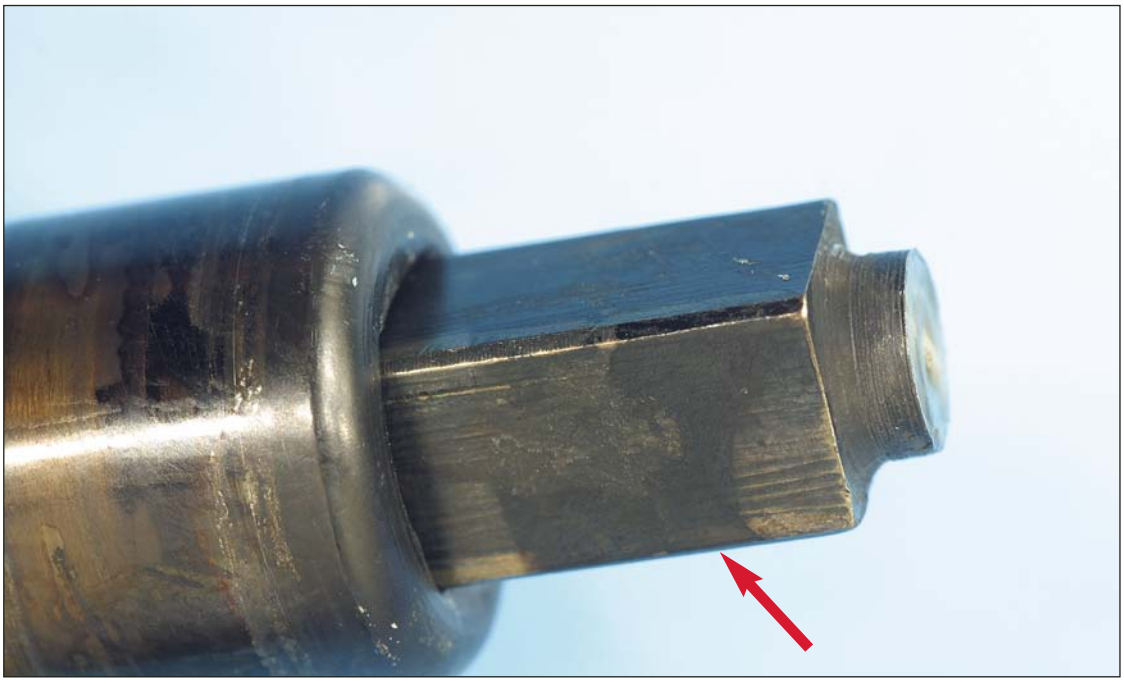


FIGURE 11: Drive coupling engaged with the accessory drive gear



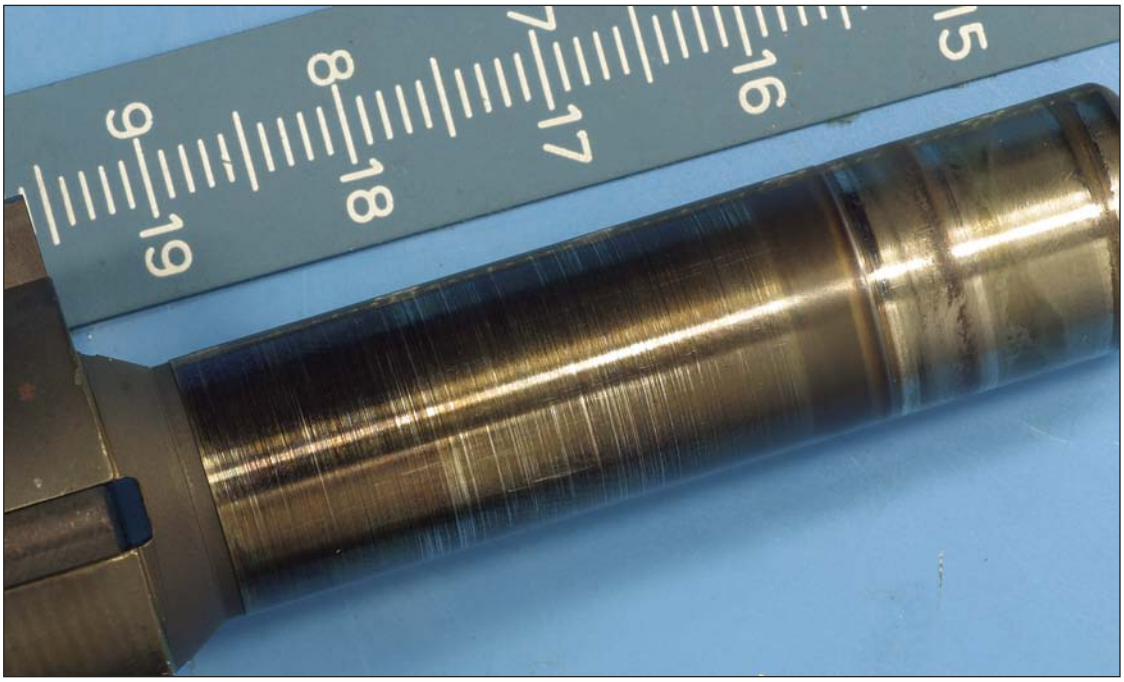
1.3.2 Left engine-driven fuel pump

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

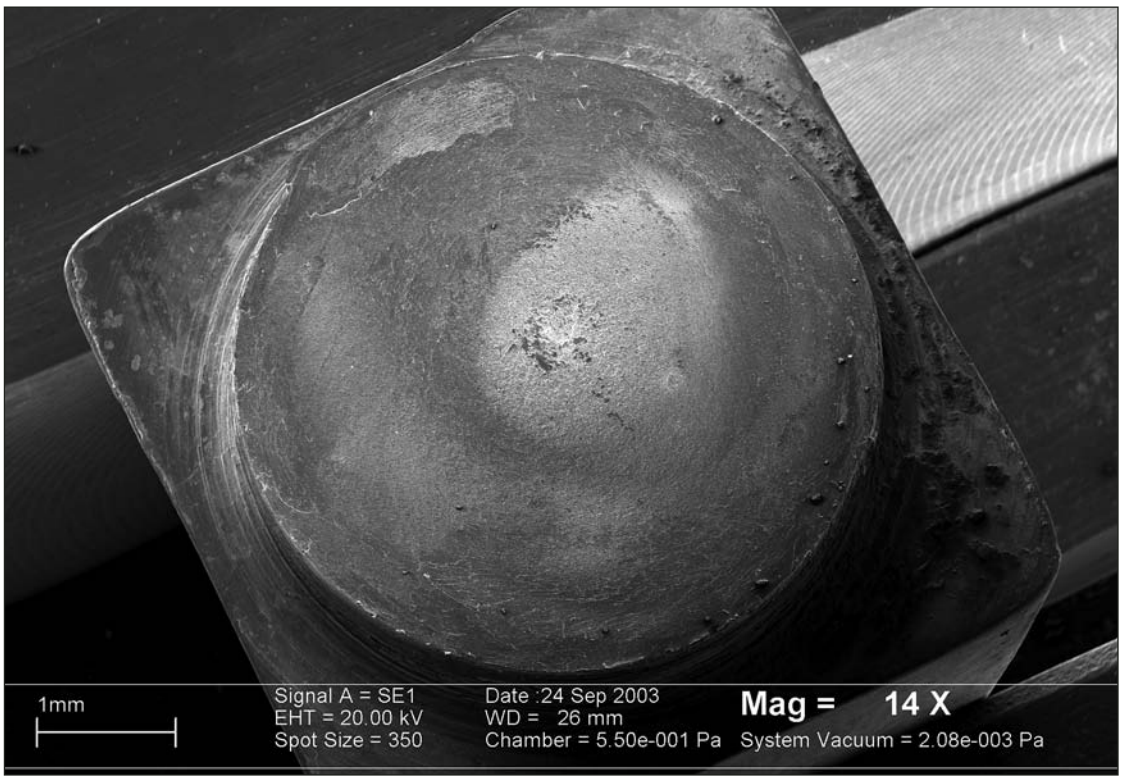


1.4 Surface characterisation

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

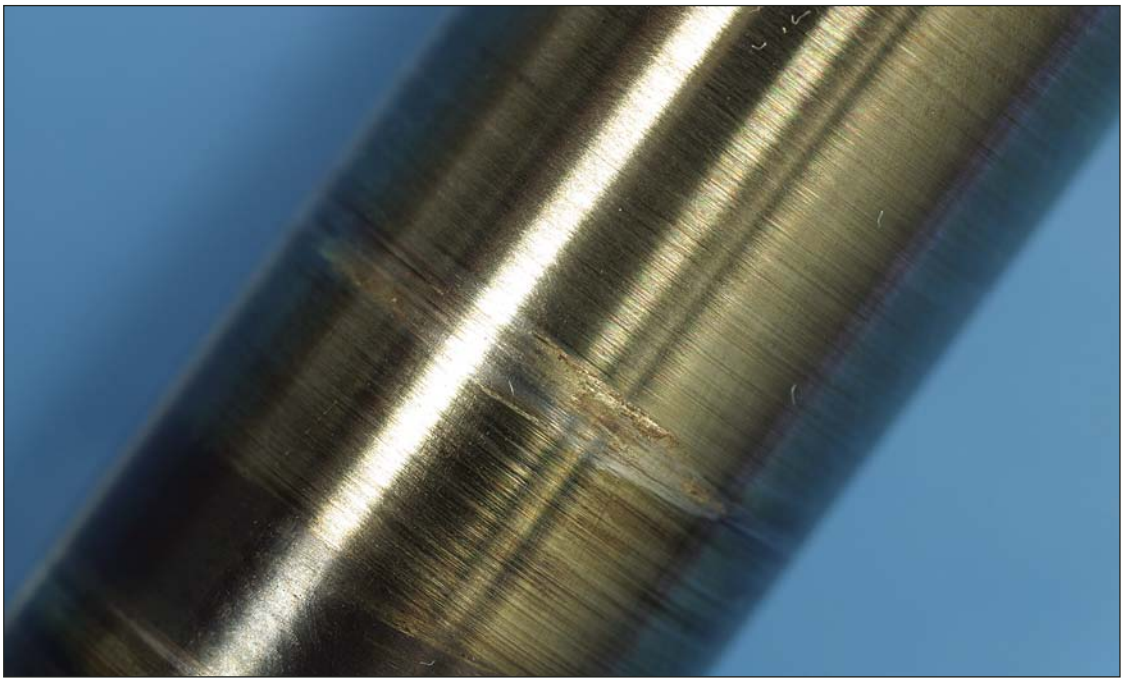
The localised areas of galling damage shown by the spindle shaft and sleeve bearing were examined optically and under the SEM. Under the optical stereomicroscope, the galled regions of the spindle shaft exhibited the circumferential ductile flow of adherent material and were typical of the damage incurred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

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



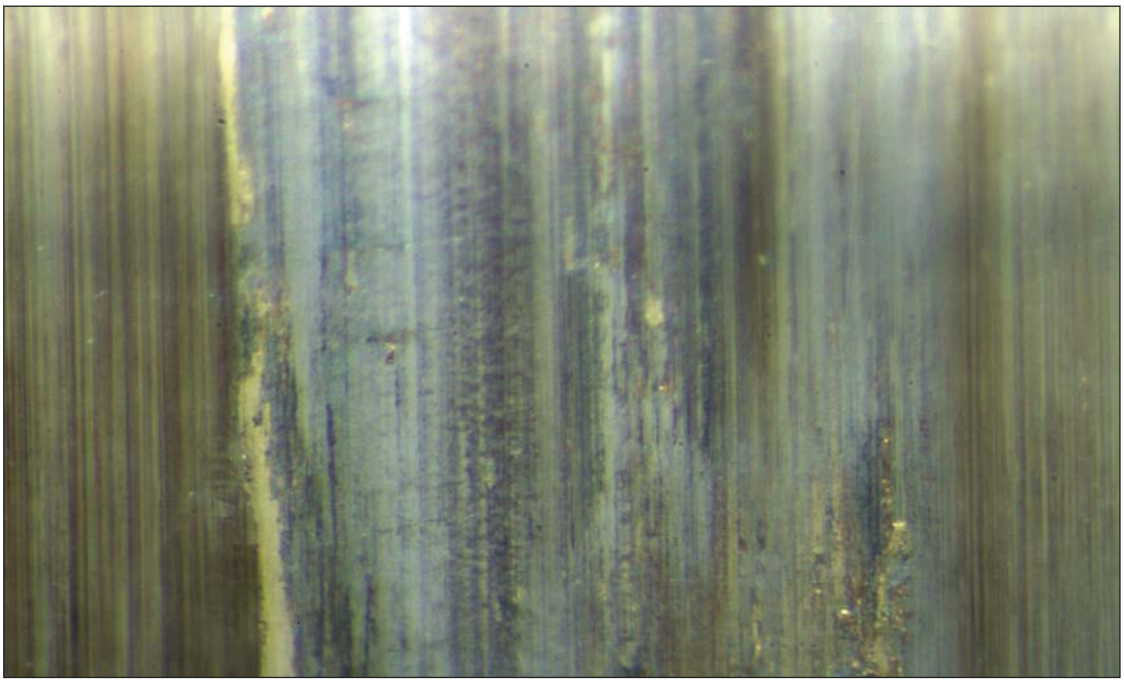
Note the circumferential flow of the polished band

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.

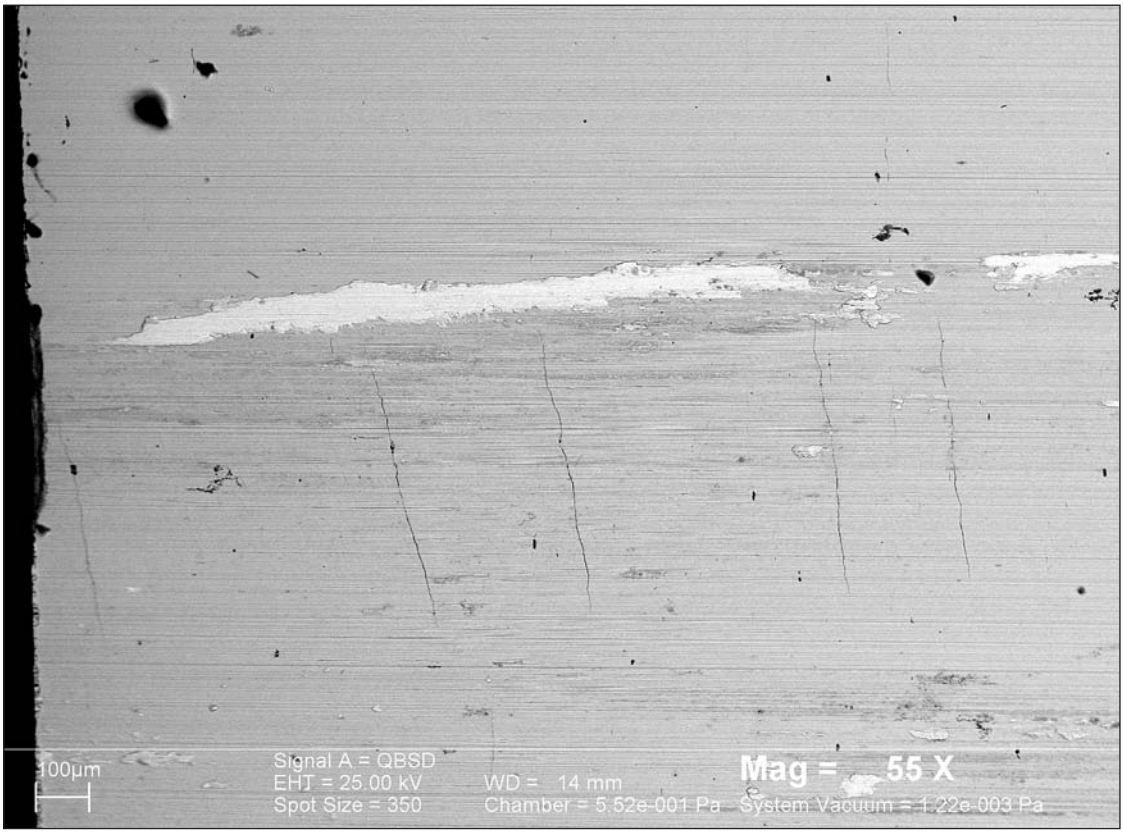
FIGURE 16: Low power optical microscope view of the damaged area shown above



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.

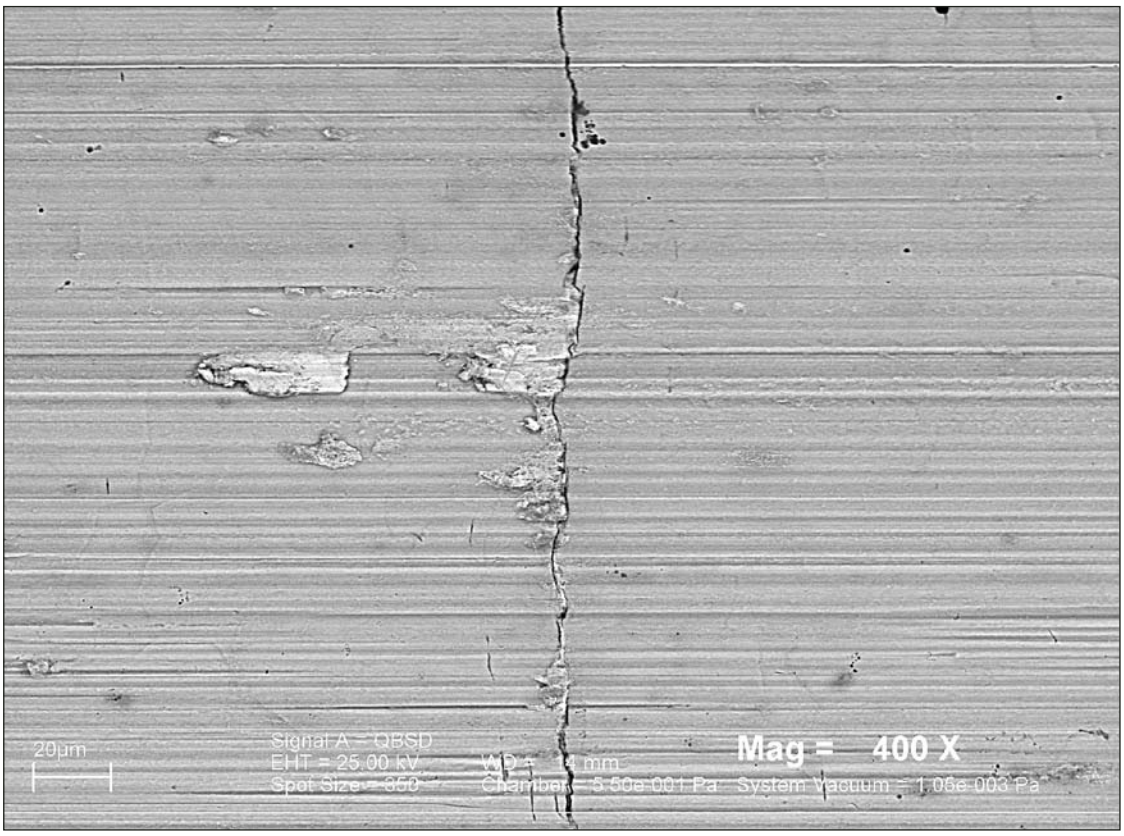
FIGURE 17: Electron microscope image of the area above



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

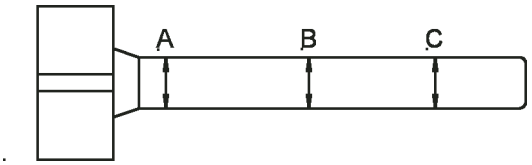
All of the cracks observed were confined to the areas of shaft surface galling and distress and did not extend onto the adjacent unaffected surfaces.

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

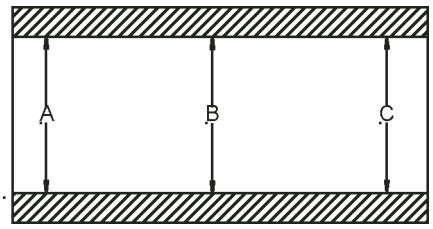
Prior to removing the sleeve bearings from the pump bodies for further study, the dimensions of the sleeve bearings and spindle shafts were measured and compared with the original equipment specifications.

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.

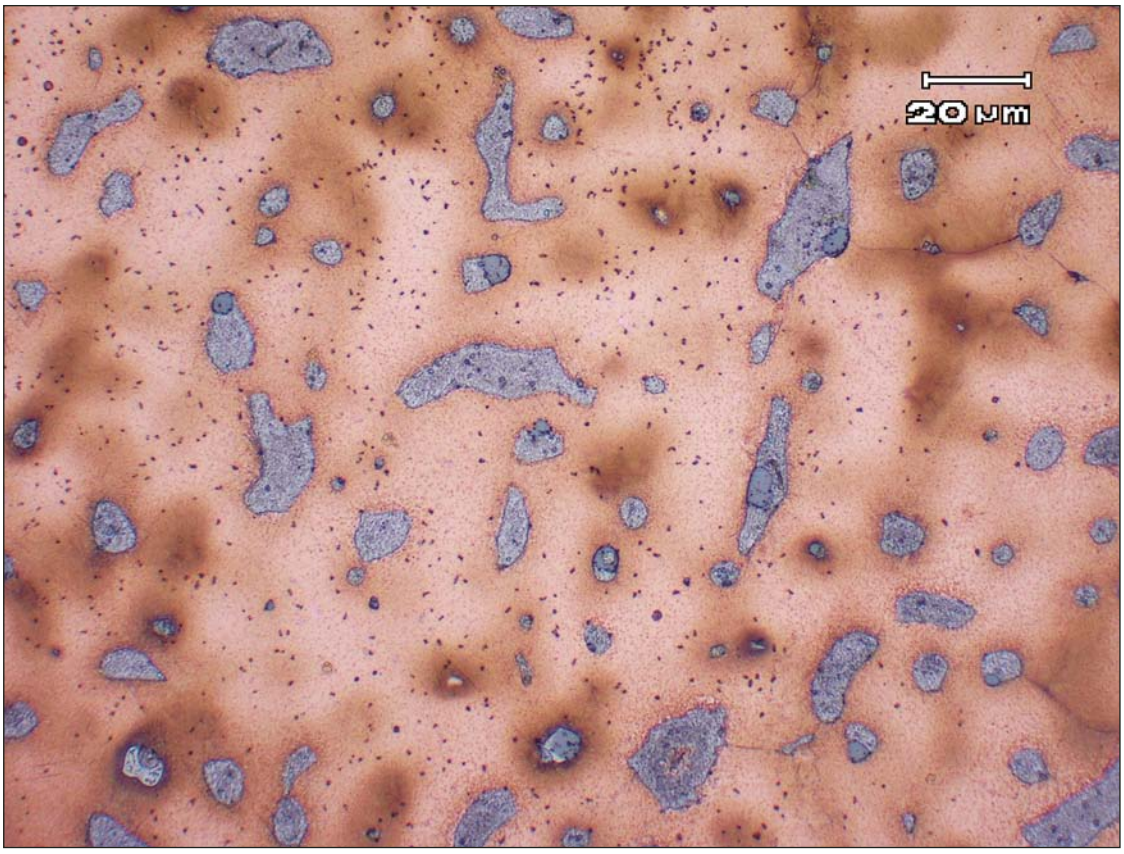
Sleeve bearing – left pump

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]

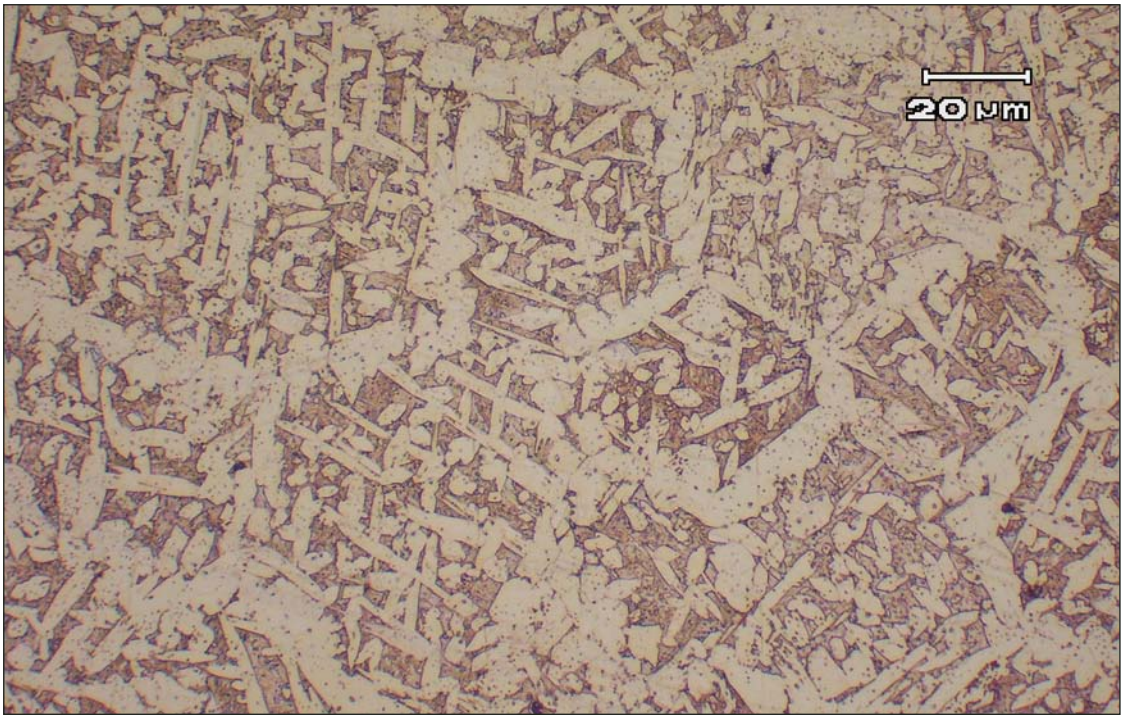


Sleeve bearing – right pump

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.

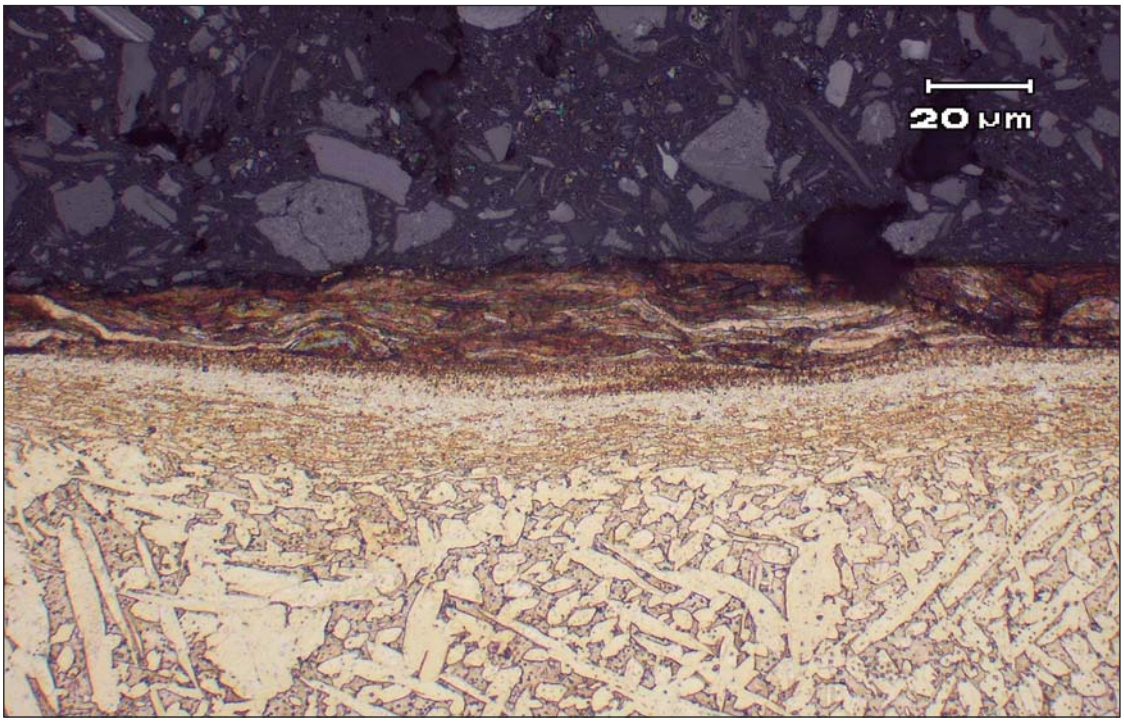
51 The structure consists of lead rich islands within a copper-tin alloy matrix – Acidic ferric chloride etch.

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]



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]

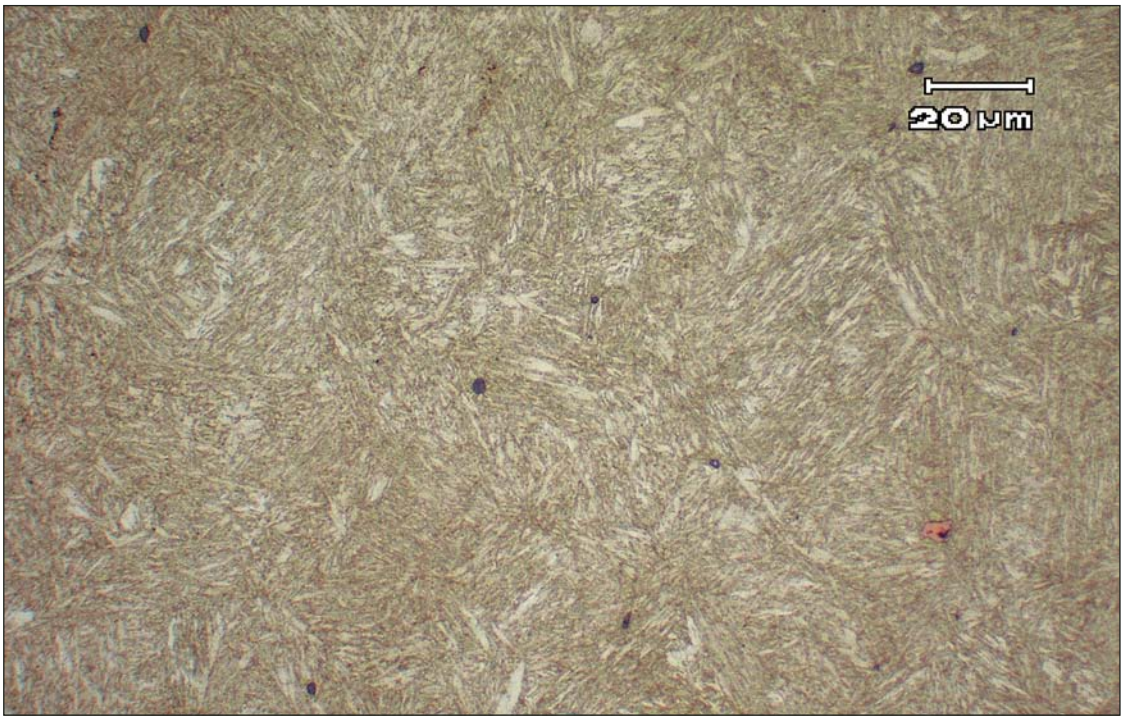
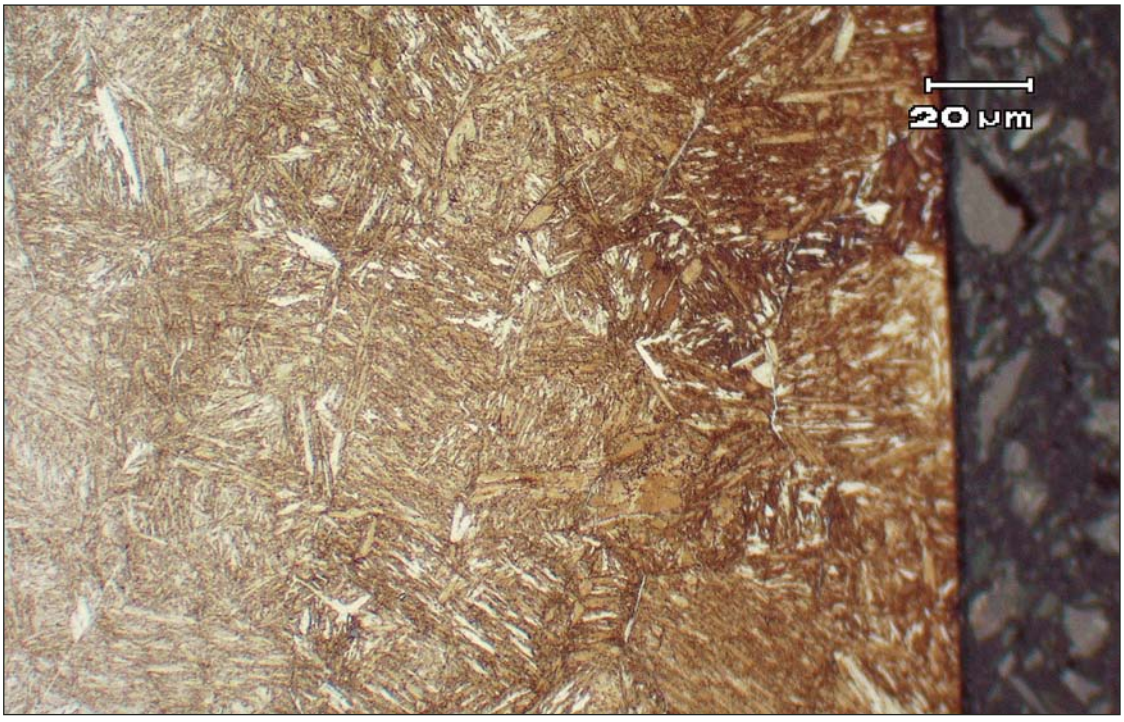


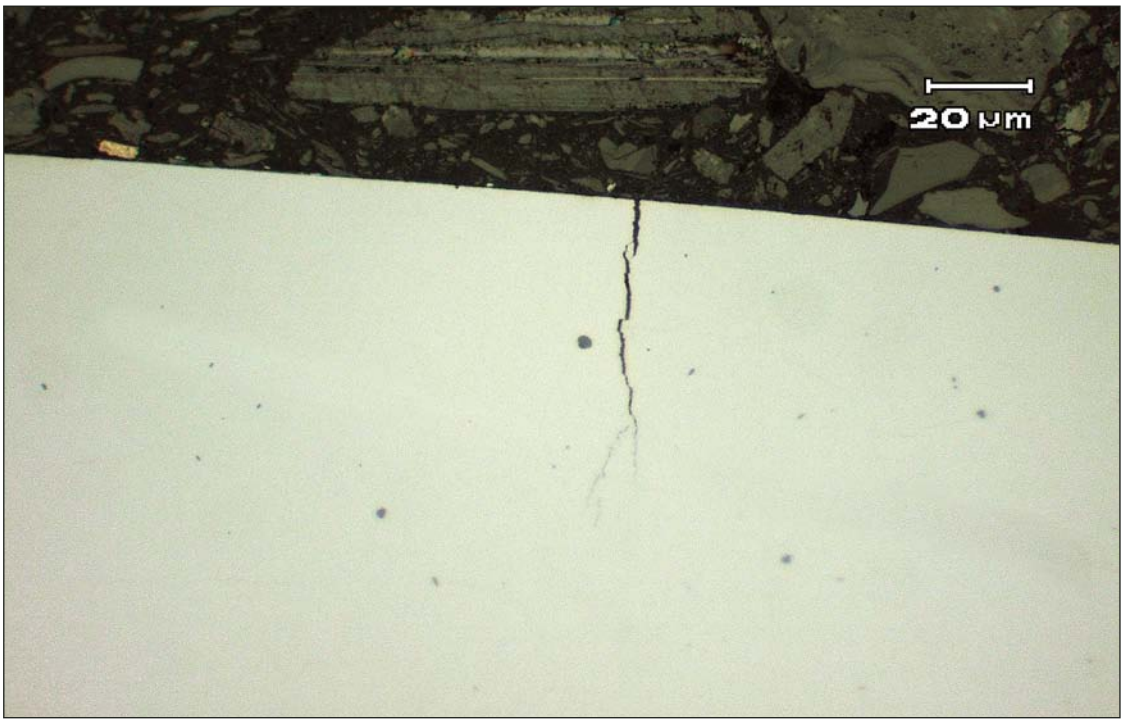
FIGURE 23: Surface microstructure of the right EDFP spindle shaft[55]



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]



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]

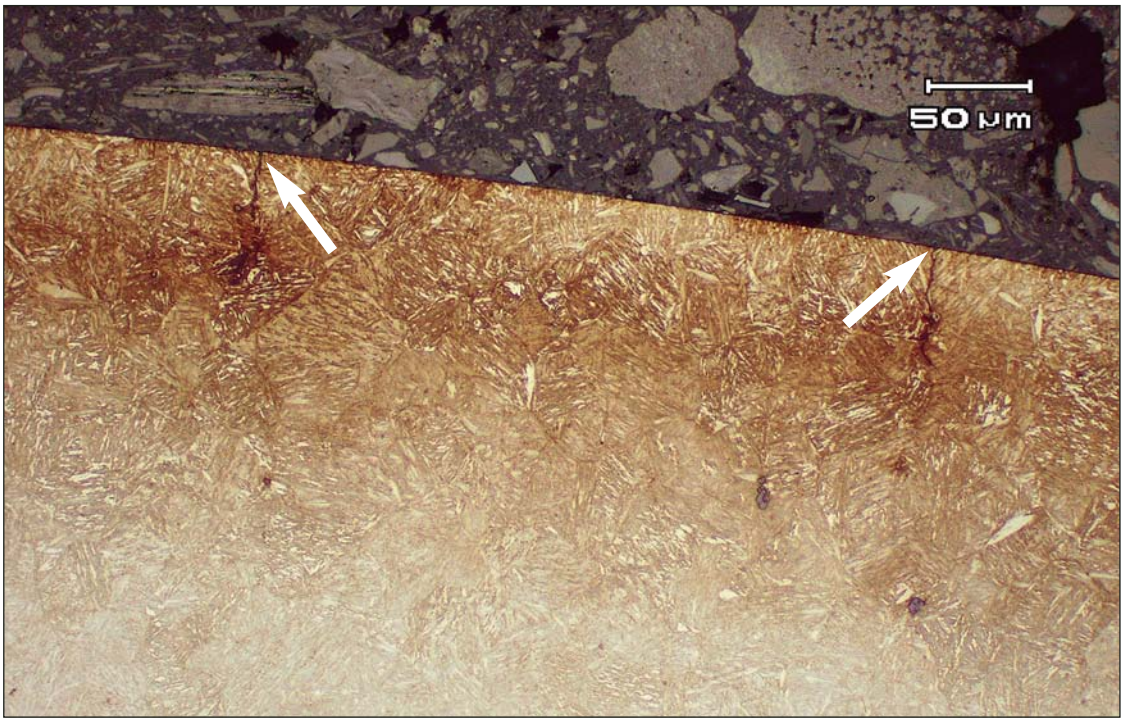
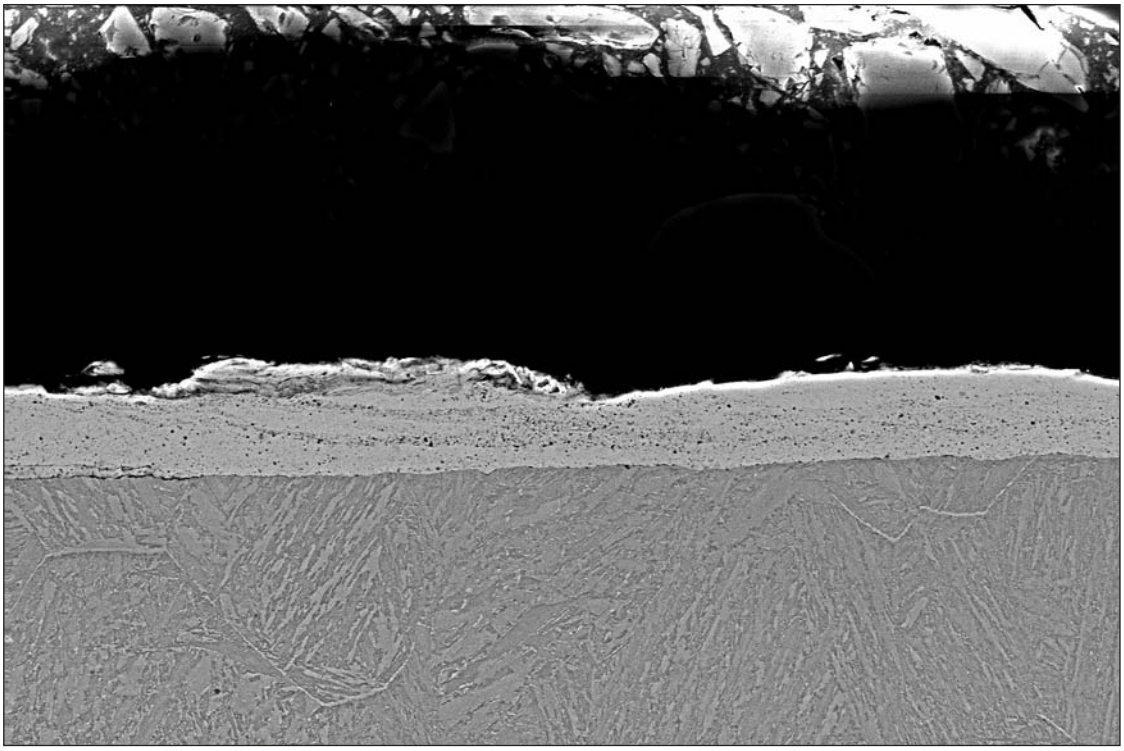


Figure 26: Electron microscope image of the surface of the spindle shaft, showing the adhesion and pickup of bronze alloy from the sleeve bearing



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

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.

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.

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_{MC}) 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.

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.

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

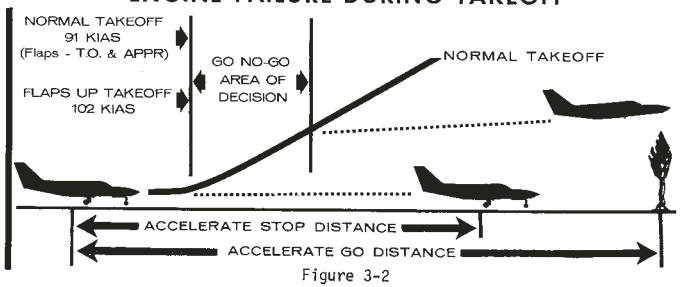


Figure 3-2

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	15,960	------
		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	4960	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

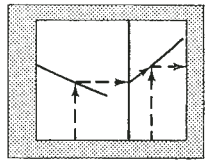
CONDITIONS:
1. 2235 RPM and 40.0 Inches Hg. Manifold Pressure Before Brake Release.
2. Mixtures - CHECK Fuel Flows In The White Arc.
3. Wing Flaps - UP.
4. Level, Hard Surface, Dry Runway.
5. Engine Failure At Engine Failure Speed.
6. Landing Gear Up Or In Transit And Propeller Feathered During Climb.
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	12,570
		4000	3820	4320	4960	5840	7180	9720	------
		5000	4090	4650	5390	6440	8170	11,940	------
		6000	4390	5030	5890	7180	9520	------	------
		7000	4730	5460	6490	8130	11,540	------	------
		8000	5110	5960	7220	9420	------	------	------
		9000	5550	6570	8160	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	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

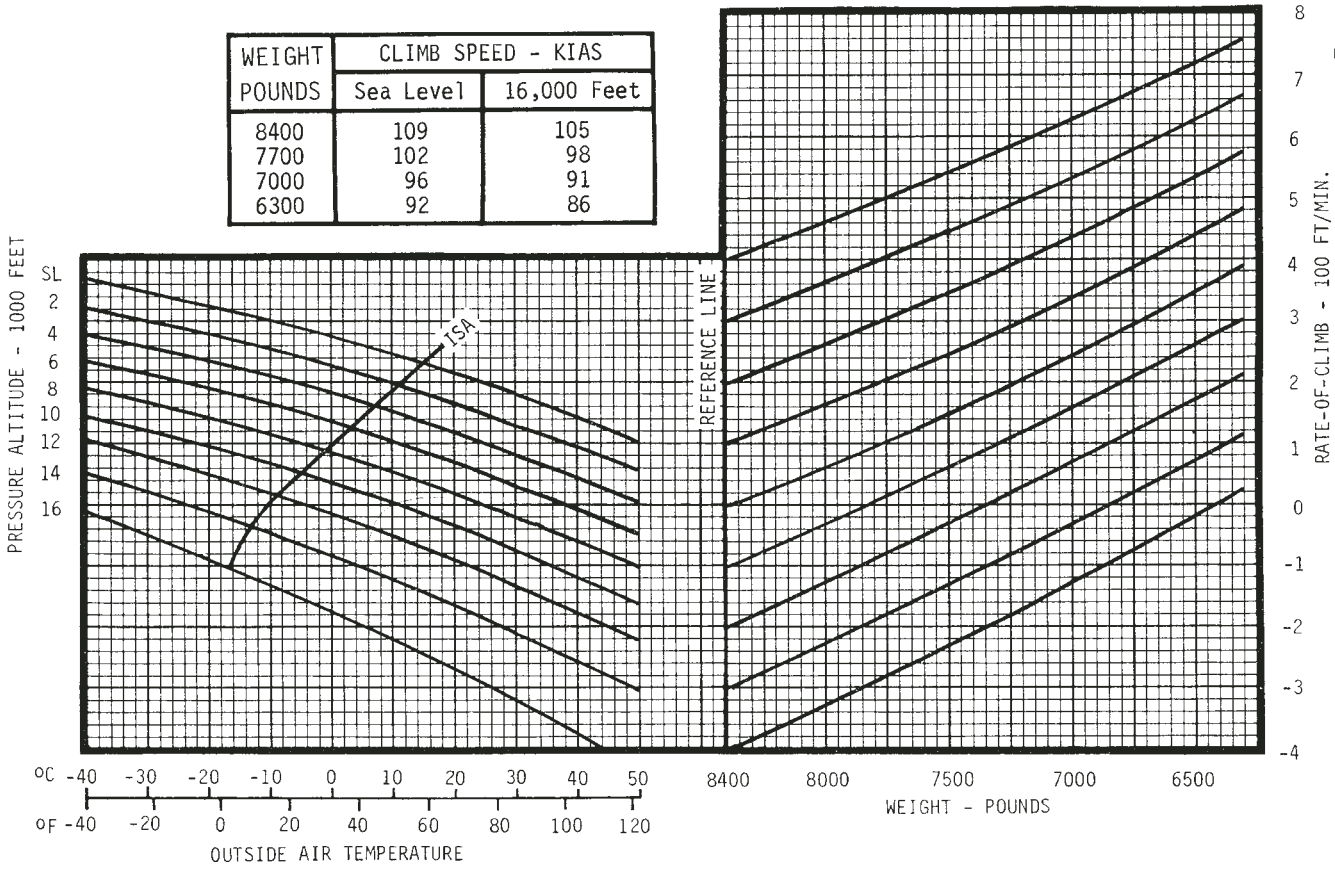


Figure 5-19

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