Australian Government
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ATSB TRANSPORT SAFETY INVESTIGATION REPORT

Technical Analysis Investigation Report – 200601291

Final

Analysis of a Fractured Fuel Injector Line, Textron Lycoming IO540-C4B5 engine

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Analysis of a Fractured Fuel Injector Line, Textron Lycoming IO540-C4B5 engine

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Abstract

A fractured rigid fuel injector line from a Textron Lycoming IO540-C4B5 reciprocating piston engine was received by the Australian Transport Safety Bureau from the Civil Aviation Safety Authority (CASA), with a request to determine the mechanism of failure and the likely contributing factors. It was reported that the line had fractured during engine operation, spraying pressurised aviation gasoline into the engine compartment. The released gasoline did not catch fire.

The line had fractured in a single location, adjacent to the union at the injector (cylinder) end. Metallurgical examination determined that the fracture was the end result of high-cycle fatigue crack growth; cracking having initiated at one of a number of large corrosion pits on the line's external surface.

Analytical techniques identified the line as a UNS S30400 austenitic stainless steel; a material susceptible to pitting corrosion attack in the presence of chlorides. Chloride compounds were detected within the corrosion pits, and were attributed to the salt-laden air associated with the coastal environment in which the engine/aircraft had been operating.

Safety action initiated as a result of the investigation findings included CASA revising airworthiness directives AD/LYC/90 and AD/CON/60; related to the maintenance of fuel injection supply lines on Textron Lycoming and Teledyne Continental aircraft engines respectively. Additionally, CASA published an information article in their periodical *Flight Safety Australia*, providing a summary of the event and investigation findings, together with advice and guidelines for maintenance personnel when installing and maintaining fuel injector lines.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

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.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

Purpose of safety investigations

The object of a safety investigation is to enhance safety. To reduce safety-related risk, ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated.

It is not the object of an investigation to determine blame or liability. However, an investigation report must include factual material of sufficient weight to support the analysis and findings. 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.

Developing safety action

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to proactively initiate safety action rather than release formal recommendations. However, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation, a recommendation may be issued either during or at the end of an investigation.

The ATSB has decided that when safety recommendations are issued, they will focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on the method of corrective action. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations. It is a matter for the body to which an ATSB recommendation is directed (for example the relevant regulator in consultation with industry) to assess the costs and benefits of any particular means of addressing a safety issue.

About ATSB investigation reports: How investigation reports are organised and definitions of terms used in ATSB reports, such as safety factor, contributing safety factor and safety issue, are provided on the ATSB web site www.atsb.gov.au.

FACTUAL INFORMATION

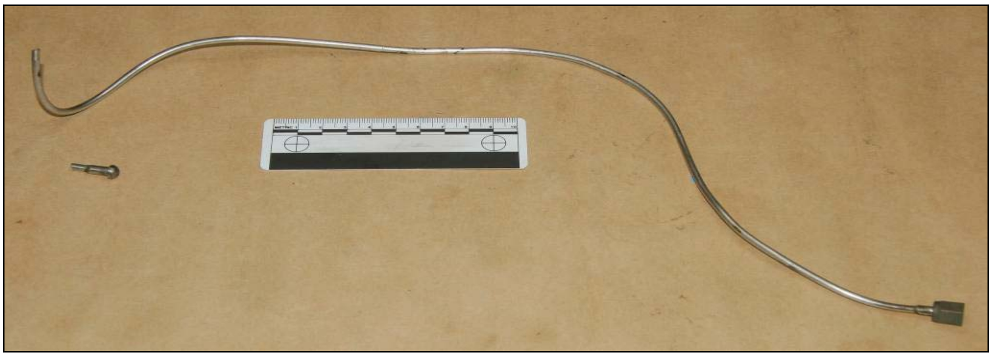
Safety issue

On 3 March 2006, representatives from the Civil Aviation Safety Authority (CASA) requested the assistance of the Australian Transport Safety Bureau (ATSB) in the technical evaluation of a fractured fuel injection line that originated from a Textron Lycoming IO540-C4B5 horizontally-opposed reciprocating piston engine. The component had been submitted to CASA after it had failed while in operation, allowing the discharge of a quantity of pressurised aviation gasoline into the engine compartment. The fuel did not ignite and there was no associated fire, despite the proximity of the fuel release and the high temperature engine exhaust components.

Component

The fuel injector line (see figure 1) was identified with the part number LW-12098-0-210 and did not carry an identifiable serial number. Information received indicated the line was installed to the number-1 cylinder of the engine, which placed it in proximity to the front of the engine cowling. The injector line's total time in service (TTIS) was not available, however it was reported that the engine from which the line was removed had operated for 1,039 hours since overhaul (TSO), with the line being a return-to-service[1] item during that overhaul. It was also reported that the subject aircraft was based in Mackay, QLD and had operated for some time in a coastal / marine environment.

Figure 1: Fractured fuel injector line, as-received

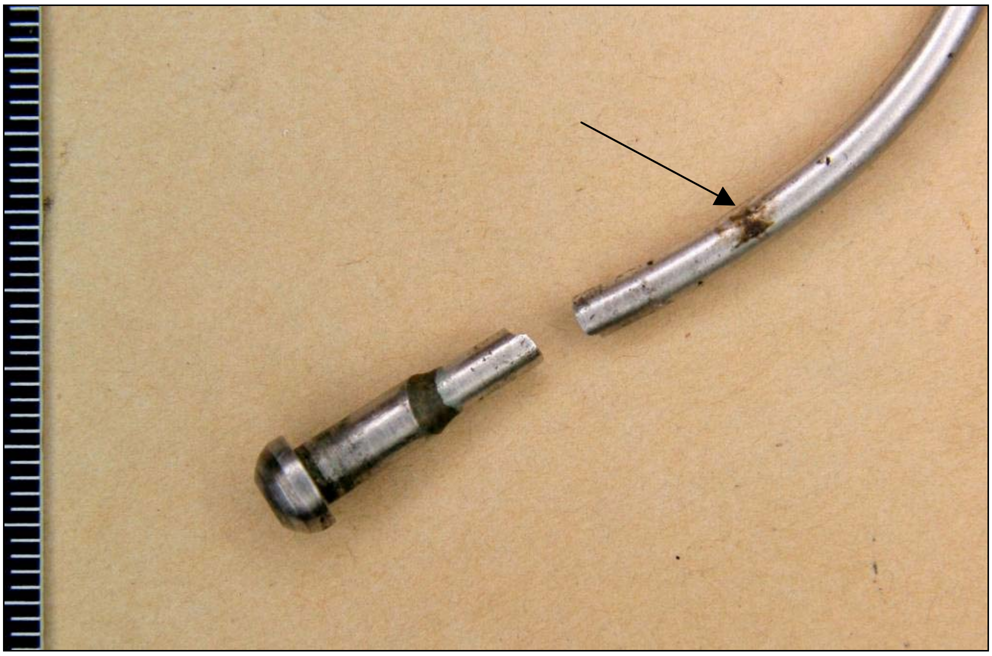


Examination

The fuel injector line presented as a formed, narrow diameter (3.16 mm) rigid metal tube, approximately 400 mm in length, with hemispherical compression nipple connections at each end. The line had fractured transversely through the plain tube section at approximately 80 mm from the injector connection (cylinder) end; the point of failure located 6.5 mm from the brazed connection with the nipple fitting (see figure 2).

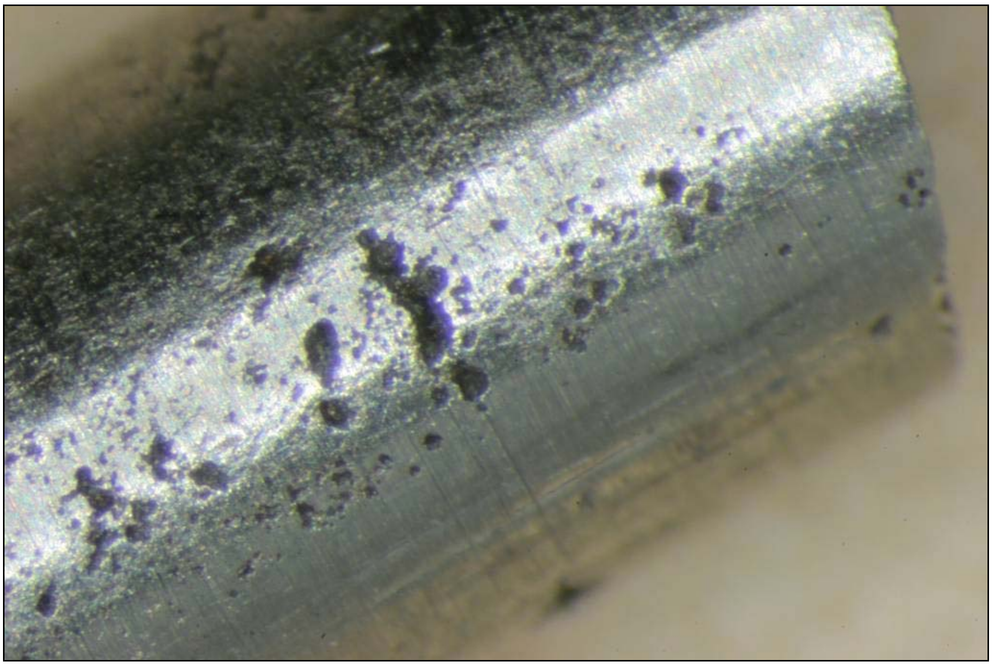
1 A return-to-service item is a component that is maintained on the basis of physical condition and may be reinstalled as part of an overhauled assembly, if its condition is assessed as suitable for further service.

Figure 2: Location of injector line fracture, with pitting corrosion staining arrowed



The external surfaces of the line showed several isolated areas of pitting corrosion damage with the associated brown oxide staining. Under low-power stereomicroscopic examination, several of the areas of pitting showed clusters of attack that had produced notable metal loss and wall penetration (see figure 3). The fillet of brazing alloy around the nipple fitting joint also showed a light surface verdigris film.

Figure 3: Pitted external surface of injector line



Under optical study, the injector line fracture surfaces were characteristically clean and undistorted (see figure 4). A vague chevron pattern extended away from a single large hemispherical corrosion pit that had been exposed by the fracture separation – the pit extending to a depth of around 75% of the original line wall thickness (see figure 5).

Figure 4: Line fracture under low magnification. Fracture origin is at arrow

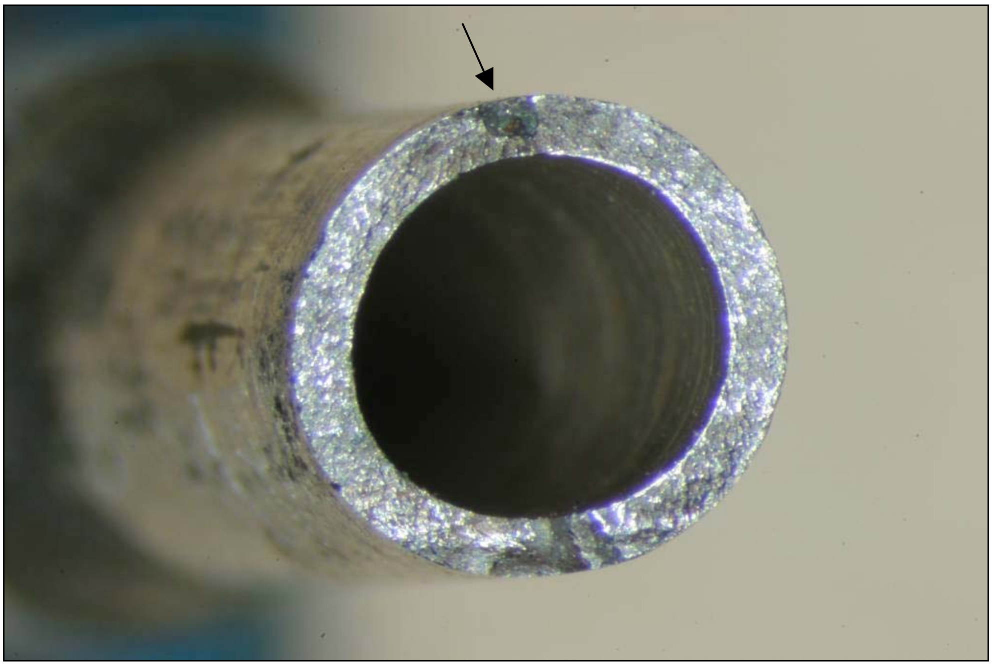
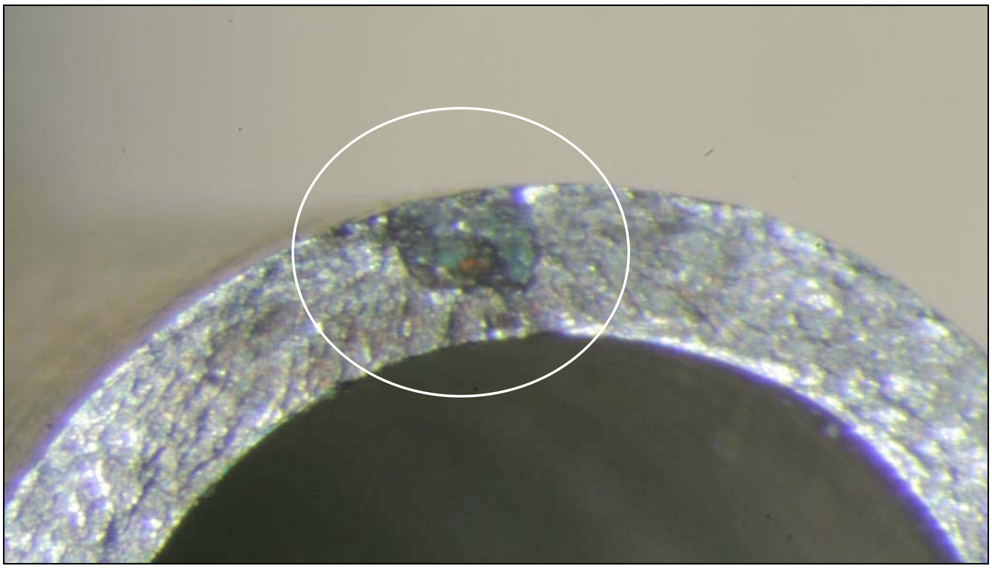
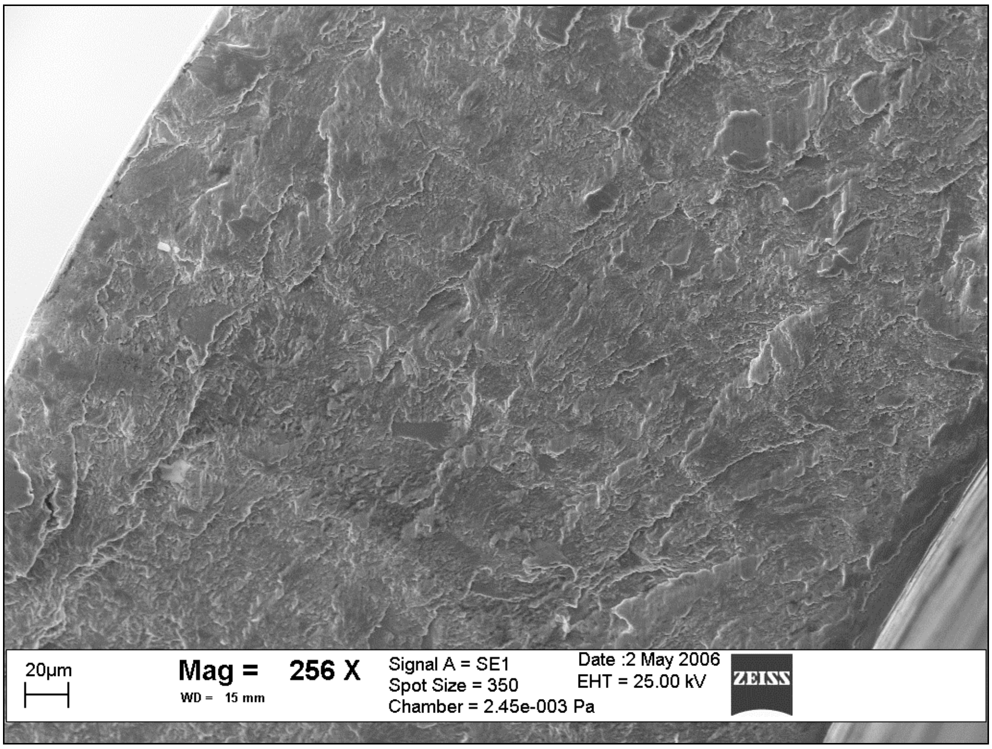


Figure 5: Closer view of the large corrosion pit identified at the fracture origin (circled)



Under the scanning electron microscope (SEM), features typical of fatigue crack propagation were found across the majority of the fracture surfaces leading away from the corrosion pit (see figure 6). The surfaces also presented mechanical smearing and flow damage, consistent with repeated contact during the crack growth phase. The finely striated surfaces and small area of final ductile fracture opposite the origin, were consistent with crack initiation and growth under low-stress, high-cycle conditions.

Figure 6: Electron image of the line fracture surface, showing vague banded appearance, characteristic of fatigue crack growth



Material analysis

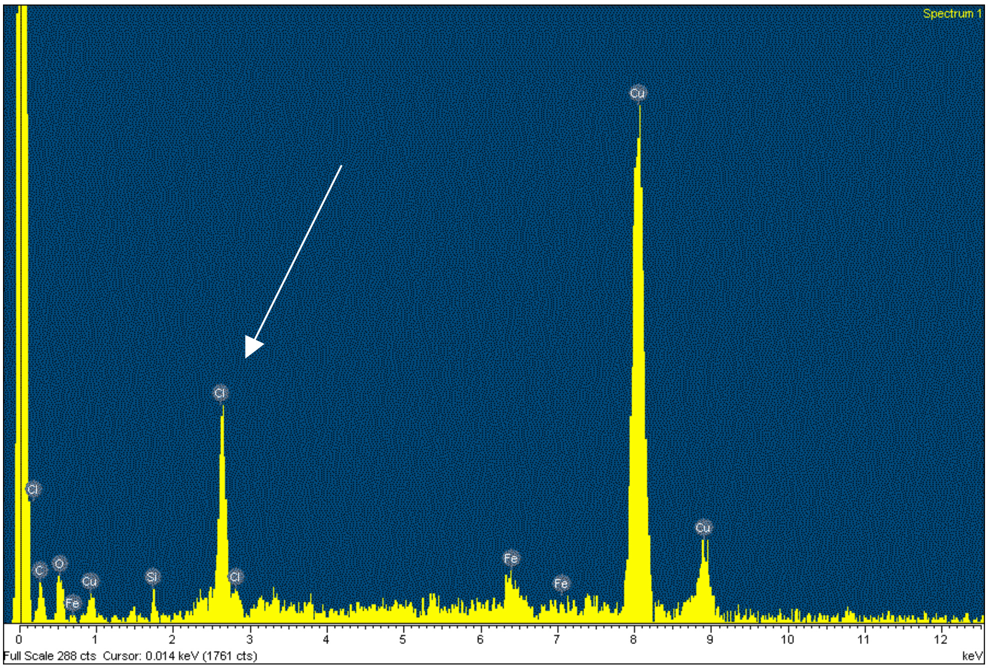
Spectrographic analysis[2] of a sample of the injector line material identified it as a Cr-Ni stainless steel alloy, meeting the general specification for a UNS S30400 / AISI/SAE 304 austenitic grade.

Corrosion analysis

Energy-dispersive x-ray spectroscopy (EDS) of the corrosion product contents of several of the surface corrosion pits, showed most to contain chloride bearing compounds (see figure 7). Chlorine is elementally foreign to the stainless steel alloy chemistry and is most typically encountered as environmentally-borne sodium chloride (common salt).

2 Analysis provided by Spectrometer Services Pty Ltd, Coburg VIC. Report number 23746 refers.

Figure 7: **EDS analysis spectrograph showing the elemental composition of the corrosion pit at the fracture origin (the chloride elemental peak is arrowed)**



ANALYSIS

Line failure

The investigation determined that the examined fuel injector line had failed as a result of a unidirectional bending fatigue cracking mechanism, initiated at a large external surface corrosion pit. The fracture features were typical of fatigue crack growth occurring under the vibratory (high cycle) loading conditions associated with normal engine operation.

Factors such as poor line support and excessive installation stress have previously contributed to high-cycle fatigue failures of rigid fuel supply and injection lines. In this instance however, the presence of significant levels of intrusive surface corrosion pitting damage would most likely have provided the degree of stress-concentration necessary for normal engine vibratory stresses to have resulted in fatigue crack initiation. The identification of a large corrosion pit at the fracture origin was direct evidence of this.

The fuel injector line had been manufactured from an austenitic stainless steel alloy, and was typical of many such rigid lines employed for delivery of pressurised fluids. Austenitic stainless steels, to varying degrees, are susceptible to pitting corrosion attack in the presence of chloride ions, with the aggressiveness of the attack being proportionate to the ambient temperature. Elevated temperatures typically accelerate rate of attack. With regard to the injector line examined, the presence of chloride compounds was confirmed within the proximity of the pits and corroded material. Given the reported operation of the engine/aircraft in a coastal region, it is probable that the chloride acting to advance the corrosion pitting had its origins in the salt-laden air of those environs.

SAFETY ACTION

Civil Aviation Safety Authority

Following the ATSB investigation of this issue, the Civil Aviation Safety Authority revised airworthiness directives AD/LYC/90 and AD/CON/60 to include requirements for enhanced visual inspection of the lines, directing specific attention to the examination of lines for the presence of pitting and corrosion damage. The amended directives AD/LYC/90 Amdt 1 and AD/CON/60 Amdt 1 became effective on 31 August 2006.

In the July-August 2006 edition of the aviation industry journal *Flight Safety Australia*, CASA published a one-page article discussing the pitting corrosion issue and providing guidance for maintenance personnel when installing and examining rigid stainless steel fuel injector lines.