ACCIDENT

Aircraft Type and Registration:	Cessna 750 Citation X, G-CDCX
No & Type of Engines:	2 x Rolls-Royce AE 3007C1 turbofan engines
Year of Manufacture:	2002
Date & Time (UTC):	9 December 2010 at 1021 hrs
Location:	Doncaster Airport, South Yorkshire
Type of Flight:	Private
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - None Passengers - N/A
Nature of Damage:	Right mainwheels detached, damage to flaps and outboard wing skin, puncture of right elevator
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	34 years
Commander's Flying Experience:	4,800 hours (of which 600 were on type) Last 90 days - 72 hours Last 28 days - 34 hours
Information Source:	**AAIB** Field Investigation

Synopsis

The aircraft was positioning to Doncaster Airport for minor maintenance. Shortly after a normal touchdown, the right main landing gear trailing link failed and both mainwheels on that side detached. The aircraft slid to a halt just off the right side of the paved surface. The link failed due to a long stress corrosion crack and a Safety Recommendation is made for frequent visual inspection of the links for the presence of such cracks.

History of the flight

The aircraft was flown from Luton to Doncaster, its maintenance facility, where it was to undergo minor preventative maintenance. The weather conditions for the flight were good, and the flight was described by the crew as normal. The aircraft was radar vectored onto the ILS approach for Runway 20 at Doncaster, and at five miles on the final approach the commander disengaged the autopilot and continued to fly the approach manually. ATC passed the surface wind as 290º at 11 kt, which was well within the aircraft's crosswind landing limit, and cleared the aircraft to land. The pilots described the approach, and the flare as normal. The landing, which was to the left of the runway centreline and within the instrument landing area, was described as smooth, although the commander recalls the right Main Landing Gear (MLG) touched down slightly before the left. He then became aware that, as the nose began to drop, the aircraft rolled gently to the right and he felt a judder through the control yoke. The commander quickly realised he had a landing gear problem and attempted to keep the aircraft straight on the runway using the left brake and rudder. The co-pilot advised ATC that they had a problem with their landing gear, and shut down the engines. As they slowed down the commander started to lose directional control and the aircraft began to veer to the right. They came to a halt on the edge of the runway. The crew shut down the remaining systems and vacated the aircraft normally.

ATC saw the aircraft land in what appeared to be a normal landing. They then noticed sparks coming from the right side of the aircraft and saw what appeared to be a wheel bouncing down the runway. They immediately initiated their aircraft crash procedures, and the fire service responded immediately, reaching the aircraft seconds after it came to a halt. They reported that a considerable amount of debris was on the runway, including both right mainwheels.

Flight Recorders

The aircraft was fitted with a two-hour Cockpit Voice Recorder (CVR) and a 25-hour Flight Data Recorder (FDR). The CVR did not highlight any issues associated with the flight, crew or aircraft until the MLG failed. It had lost power when the crew shut down the aircraft electrical power shortly after the aircraft came to rest. The FDR provided good data relating to the accident.

The aircraft took off from Luton at 0950 hrs, climbed to FL120 and headed for Doncaster. The aircraft was fully configured for landing, with gear down, 35° of flap and the autopilot disengaged by 1,600 ft amsl on the approach. The aircraft descended with minimal deviation from the glidepath with approximately 10° of left drift.

From a height of 120 ft the pitch was increased and the rate of descent reduced. Figure 1 shows the pertinent FDR parameters from just before touchdown. The heading was gradually reduced and just before touchdown the aircraft started to drift left of the centreline.

The aircraft initially touched down with a descent rate of approximately 100 ft/min with a small amount of right roll and a small, but increasing, fly-right localizer deviation. The nose was lowered, during which small lateral acceleration oscillations were recorded. During the period when the Weight On Wheels (WOW) parameters became active, the aircraft started rolling right. The pitch reached zero and the speed brakes were deployed. When the roll reached approximately 5º, a 1.9 g spike in normal acceleration and a -0.35 g spike in longitudinal acceleration were recorded.

There were no brake related parameters recorded.

Passing through a ground speed of 90 kt the thrust reversers were deployed for approximately three seconds. The heading remained stable until the ground speed reduced through 30 kt, when it started yawing right. This was corrected by deploying the left thrust reverser for approximately three seconds. Passing through 20 kt the right engine fuel flow quickly reduced to zero; the fuel flow for the left engine also reduced to zero over the next five seconds. Just before coming to a complete stop the aircraft yawed right.

Flight Recorder analysis

It is likely that the gear detachment occurred during the initial touchdown phase, with a low descent rate. Just prior to this, whilst drifting to the left, small oscillations in the normal and lateral acceleration parameters were recorded, possibly associated with intermittent contact with the runway or ridges of ice observed on the

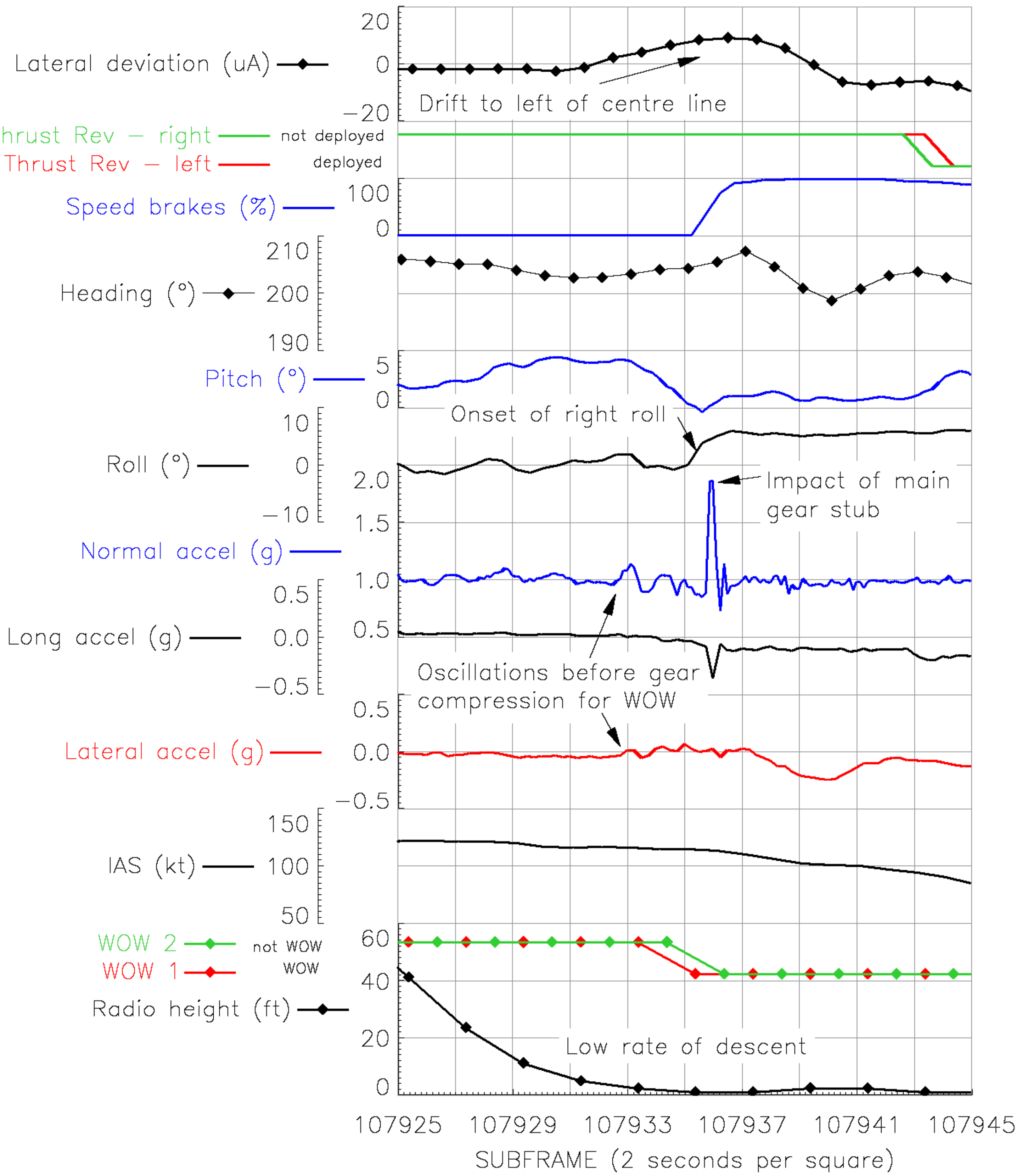
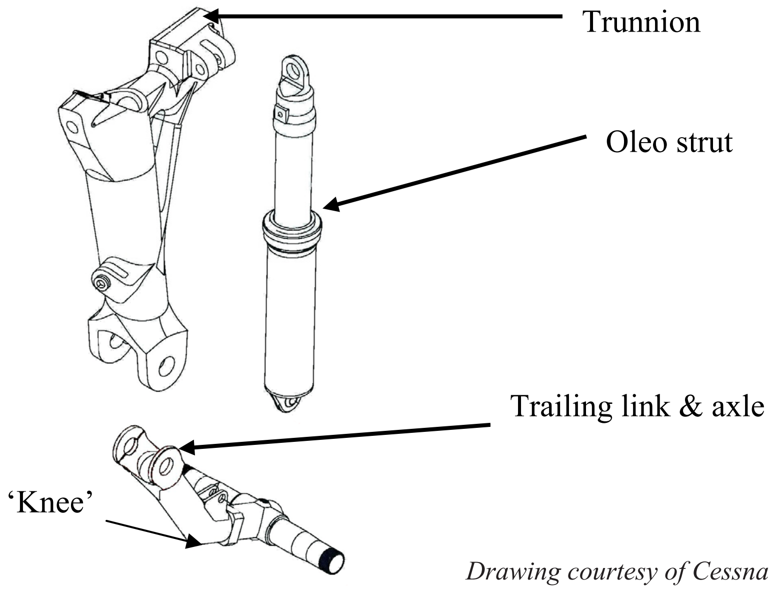


Figure 1

Pertinent FDR parameters from just before touchdown runway. A right roll initiated with the failure of the gear component and the accelerometer spikes were the result of the aircraft rolling onto the remaining structure after the wheel assembly had detached.

Description of the Citation X Main Landing gear (MLG)

G-CDCX used a 'trailing link' design (part number 6741013-3) of MLG. The vertical cylinder, incorporating the retraction trunnion, at the top, has the trailing link articulated at the bottom (Figure 2). At the rear of the link, the axle for the double wheels is pressed and bolted into it and a lug roughly in the middle serves as the attachment for the oleo shock absorber strut. The change in angle of the axis of the link at this point is referred throughout this description as 'the knee'.



Drawing courtesy of Cessna

Figure 2
Citation X Main Landing Gear

The wiring harness for the anti-skid transducers runs inside the trailing link and, at the forward end, emerges through a closing end cap and a grommet which is additionally sealed with a flexible sealant to keep moisture out of the interior. The link itself is made from a 300M forging, an ultra-high tensile strength steel which, after machining where necessary, is shot-peened, grit-blasted and cadmium plated. The interior of the link bore is then finished with a corrosion-resistant chromate primer whilst the exterior is primed and finish-painted.

Examination of the aircraft

The aircraft was examined by the AAIB in the late afternoon of the day of the accident. It had come to rest just off the paved surface to the right of the runway, having turned through about 45° to the right. The ground was frozen hard and there had been no sinking of the wheels into the grass. The aircraft was resting on its right wingtip and flaps and the remains of the MLG vertical cylinder, which had been partially ground away by runway contact, obliterating the trunnion forks which locate the forward end of the trailing link. There was also a small puncture of the right elevator.

Examination of the runway marks could not identify the first touchdown point but, close to the touchdown area, twin gouges caused by the trunnion forks could be seen, becoming a broader, single scrape mark as the forks wore down. Towards the end of the ground slide, further marks were made by the outboard flap and wingtip. It was noted that the commencement of the gouge marks from the right MLG was about one metre to the left of the runway centreline, indicating that the aircraft had been displaced to the left on touchdown. However, this was not considered to have had any bearing on the failure.

Debris was found along the length of the ground slide marks, the largest being the two mainwheels, with most of the fractured trailing link, and the shock absorber oleo strut. Most of the remaining debris was small, comprising clips, hydraulic piping etc. but included the fork fitting of the failed trailing link, together with the trunnion pin, which had been ground down to about half of their diameter.

It was apparent that the trailing link had fractured in a roughly circumferential manner at its forward end although, at the upper surface, the fracture surface turned aft towards a longitudinal crack which ran for some 27 cm (Figure 3) along the top surface. Evidence of a darker area where the longitudinal crack met the circumferential fracture suggested that the crack pre-existed the final fracture and that it was responsible for an overload failure of the component. This was later confirmed by metallurgical examination.

Detailed examination

The failed link was transported to a metallurgical laboratory for expert examination in the presence of a specialist from Cessna Aircraft Company. One of the first actions was to section the link longitudinally, so that the interior of it could be examined (Figure 4). The crack on the upper face could clearly be seen, as could an extensive area of corrosion and loose paint in the vicinity of the knee, again on the upper surface. The lower half of the link appeared crack and corrosion-free with no loss of paint. However, there was an apparent black stain, suggesting long-term pooling of some liquid – this would later be examined to discover its nature.

A few centimetres of uncracked material held the two halves of the upper segment together, so this had to be sawn and then broken apart in order to examine the crack faces. As can be seen in Figure 5, the faces were heavily corroded and it was not possible to identify

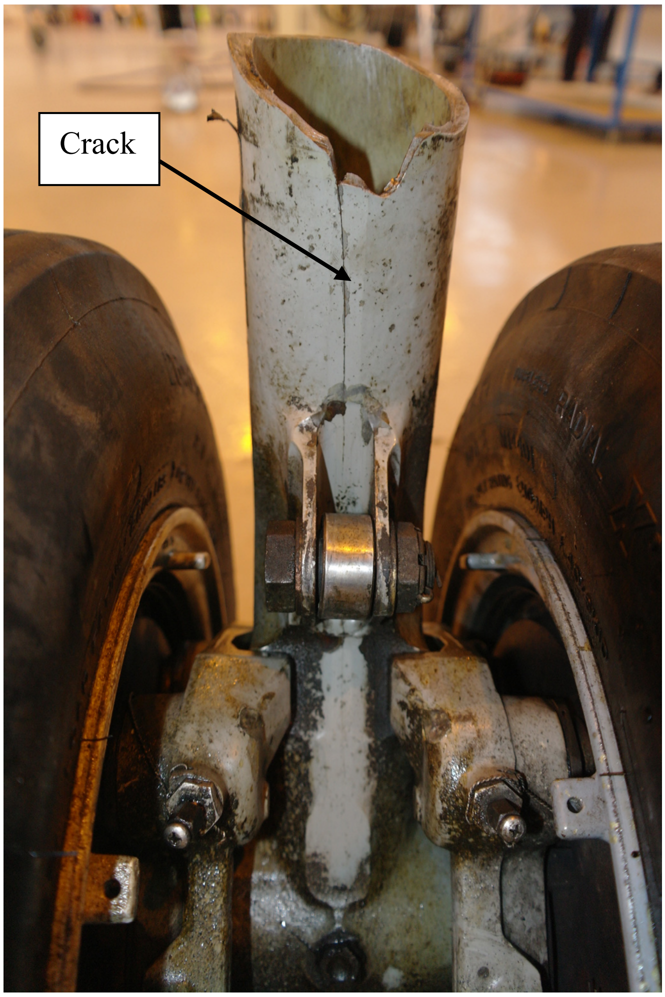


Figure 3

Broken trailing link showing circumferential facture and longitudinal crack on upper face

precisely the origin of the crack but, judging by the varying degrees of severity of the corrosion attack, it was judged to have been just forward of the knee on the inner surface, propagating forward and aft from this point simultaneously until the total crack length reached approximately 275 mm, at which point instantaneous rupture of the forward part of the link occurred in a circumferential direction. Sections placed in a Scanning Electron Microscope (SEM), showed that the crack had propagated through Stress Corrosion Cracking (SCC).

The area of paint loss and surface corrosion was also closely examined. This was found to be severe, with

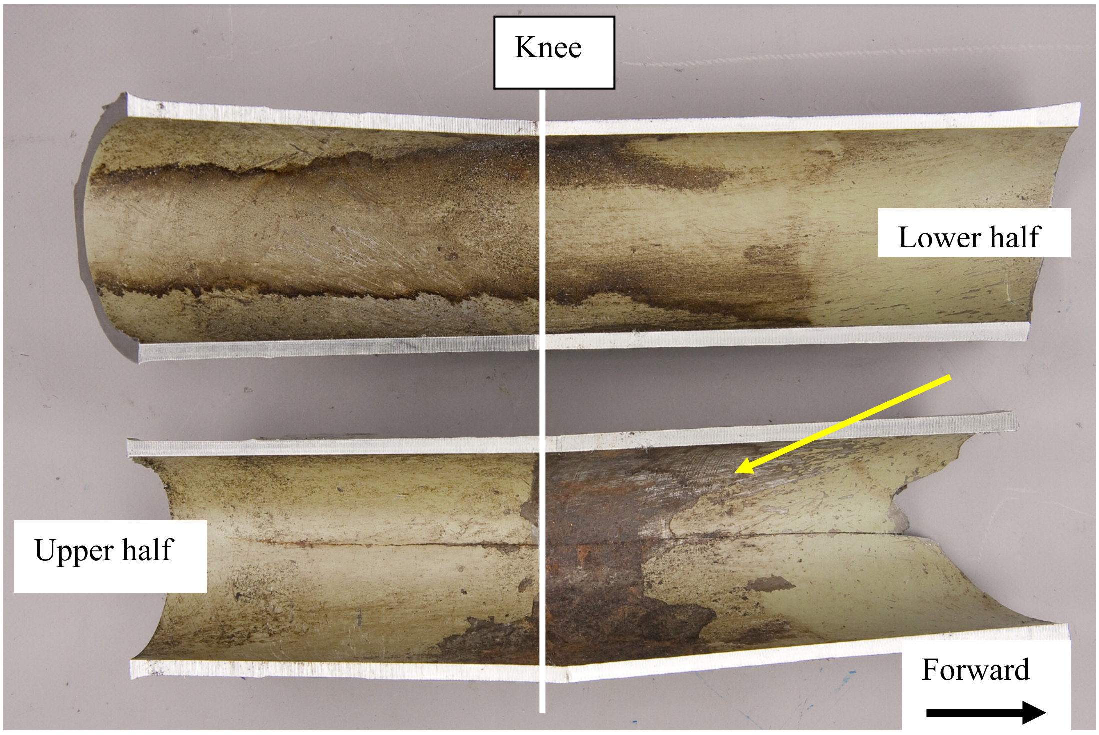


Photo courtesy of QinetiQ

Figure 4

Longitudinal section through failed link showing extent of crack and corrosion on upper half and staining on lower half. Note scratches (arrowed)

Photo courtesy of QinetiQ

Figure 5

Picture of SCC showing probable area of origin complete loss of the cadmium plating and deep pitting of the base metal. Also noted was a series of roughly longitudinal scratches in the paint (Figure 6), which appeared relatively fresh and were thought to have been caused post-failure of the link, possibly by scooping-up runway debris. However, microscopic examination showed that similar marks appeared in the heavily corroded region in a similar orientation, manifesting themselves as linear regions of deeper corrosion. Furthermore, the 'fresh' scratching appeared to run under a region of black staining, similar to that which was noted on the lower half of the link.

Photo courtesy of QinetiQ

Figure 6

Close-up of longitudinal scratches

Chemical samples were taken to try and establish the nature of the black staining. The first observation was that the stain was very persistent – it remained despite the fact that both upper and lower sections of the link had been washed for more than an hour in a hot detergent ultrasonic bath as part of the initial forensic examination. It comprised small particles which were analysed to contain carbon (a possible residue from oil or grease) together with compounds such as aluminium silicate and calcium carbonate and elements found in the primer paint. Other elements which would be expected if the stain contained oil or grease residue were not, however, detected.

Away from the corroded area, further sections were taken to measure the thickness of plating and paint on the interior and exterior surfaces of the link; both recorded average values of 38% (exterior) and only 21% (interior) of the minimum drawing requirements for plating thickness. The primer was measured to be an average of 40 microns thickness.

The base 300M steel was found to be within drawing specifications with respect to dimensions, composition and mechanical properties.

Examination of the left MLG trailing link

The left MLG trailing link was examined using a borescope and was found to have a patch of corrosion in the same area as the right link, but apparently not as severe or extensive, and with no obvious signs of cracking (Figure 7). It was despatched to Cessna for detailed examination, where it was prepared for examination in a similar manner to the right link.

When the corroded area was examined using an SEM, it could be seen that some micro cracks (identified as SCC) were growing from some of the deeper corrosion pits. There was also some external surface corrosion on the outside diameter of the link, between the oleo attachment lugs, but no cracking was present.

It was also seen from visual examination that the internal diameter of the link had been recoated with primer over a wide area around the area of corrosion, appearing to be a darker shade compared with the original paint. This was clearly a second coat applied after a corrosion repair which was performed in October 2004, after an inspection to comply with an Alert Service Letter (ASL) 750-32-19, but much of the chromate had leached out and adhesion was extremely patchy, despite it being of the correct type of primer. Little is known about this repair beyond the fact that it was found to be necessary and had been dressed-out with the correct grade of abrasive pad and primer re-applied.

Photo courtesy of Cessna

Figure 7

Interior of left link at the knee, showing corrosion and flaking of re-applied primer

The thickness of the plating was measured away from the damaged area and, like the failed right link, was found to be well below the minimum drawing requirements on the internal diameter. On the external surface, it was found to be satisfactory.

As with the right link, the 300M material was found to be within specification.

Maintenance and inspection requirements

In August 2004, Cessna issued an Alert Service Letter (ASL) 750-32-19 to all Citation 750 operators, the contents of which were classified as 'mandatory'. It required that, for aircraft with more than 3,000 total landings or aircraft bearing Manufacturer's Serial Numbers (MSN) 0044 through 0079, an inspection be performed on the MLG trailing links within 50 landings, and on all aircraft with less than 3,000 landings, within 100 landings. G-CDCX was MSN 0194 and at the time of the accident had completed 1,931 landings.

The inspection comprised a flexible borescope examination of the interior of the link, via the hole through which the anti-skid wiring passes at the front of the link, and was specifically looking for small 'craters' on the inner wall. Although the ASL did not state the origin of such craters, it was known to be a possible defect during plating of the interior in which the electrode wire may have come into contact with the link material, causing an arc and damage to the surface.

Although ASL 750-32-19 was intended to be a 'once-off' inspection, in November 2005 a further ASL, 750-32-22, was issued and which again was considered mandatory. The ASL called for a two-part inspection of the trailing link '*for pits, corrosion and cracks*'. Part one of the inspection was an external visual examination of the link using a high-intensity torch; having cleaned the area with a degreasing solvent, particular attention was to be paid to the area close to or between the oleo attachment lugs, since cracks were known to originate in that area. This inspection was to be accomplished within 5 landings of receipt of the ASL. Part two of the procedure was essentially a repeat of the borescope inspection required by ASL 750-32-19 and was required to be performed by two independent inspectors before 50 landings had been accomplished. This time, however, cracks and corrosion were mentioned as well as the arcing marks. Also, this ASL gave details of a 'repair scheme' should corrosion (presumably superficial) be found, essentially allowing the removal of the primer paint and any corrosion using a fine grade of 'Scotch-Brite' abrasive pad. If this was necessary, then the primer finish was to be restored by hand touch-in.

ASL 750-32-22 also advised operators that the 'craters', were caused by possible contact and arcing between the anode used in plating the interior and the link and could lead to:

> *'fatigue cracks along the length of the training link if they go undetected.'*

Shortly after this, in January 2006, the trailing link internal inspection was incorporated into the Model 750 Aircraft Maintenance Manual (AMM) as part of task 32-90-10-210 'Main Landing Gear Detailed Inspection' with a repeat interval of 36 months. In this case, no cleaning or repair was allowed and any findings, positive or negative, were to be reported to Cessna.

In addition a requirement existed in the AMM as part of task 32-10-00-210, to:

> *'Visually inspect the main gear assembly and trunnion for security of attachment, cleanliness, corrosion, missing or damaged components, cracks, gouges, nicks, fluid leaks and evidence of damage.'*

The periodicity of this inspection was 24 months.

According to its technical records, G-CDCX had accomplished ASL 750-32-19 in October 2004 and ASL 750-32-22 in November 2005. Two AMM internal trailing link inspections were carried out in August 2006 and February 2009.

Previous cases of cracks/corrosion in Model 750 trailing links

Information from Cessna is that they are aware of 33 cases of trailing link internal corrosion being discovered over the past three years. In total, they knew of three cases of cracked links including G-CDCX, two being SCC and the other being due to fatigue caused by the plating craters which led to the issue of ASL 750-32-19. It was noted that two (one fatigue and one SCC) had led to failure of the link whilst the third crack was found on a walk-round inspection and was only slightly shorter than the one which existed on G-CDCX's right trailing link.

Discussion

Had the left MLG link remained in service, it could have developed a major stress corrosion crack which may have also run to failure.

However, this link had had some removal of the primer to address corrosion in October 2004 – this might explain why it corroded again, due the possibility that the already sub-thickness plating was removed by the abrasive pad with no means of replacing it and given the difficulty inherent in trying to touch-in the primer by hand in the region of the knee. This 'repair' option does not form part of the current AMM procedure.

There is no record of such a repair for the failed right MLG link but the corrosion was much more advanced and a lengthy stress corrosion crack had developed. With this component, it could have been that the scratching damage found during this investigation was responsible for the initial development of corrosion. Two possibilities were considered, the first being that insertion of the borescope probe to inspect as prescribed by the ASLs and the AMM had damaged the paint and plating. This appeared unlikely given that the borescope recommended by Cessna had a relatively soft-coated probe head; the actual equipment used in the inspections is unknown. The second possibility arises from anecdotal evidence that if, for any reason, it becomes necessary to remove and replace the anti-skid wiring harness, it can be a difficult operation and some mechanics may resort to using metal wire to guide the coiled loom through the small apertures. Whatever the damage mechanism, the importance of taking precautions not to scratch the surface of the link interior must be stressed.

It appears that corrosion is the biggest threat to integrity of the link. Initially, small craters created during the plating process were thought to be responsible but corrosion pits can also initiate fatigue and now SCC. How the necessary tensile stresses for either fatigue or SCC are generated on the top surface of the link is unclear, for it would seem to experience largely compressive loading with the aircraft on its wheels. Equally the cases of corrosion discovered all appeared to be on the top surface, since it might be expected that the bottom surface would be more prone to pooling liquids and hence longer exposure to a corrosive environment. This again points to damage to the protective finish during maintenance as a possible instigator, perhaps due to difficulty in negotiating the bend at the knee.

The question of how long the corrosion and crack existed before failure of the link was considered. It has to be assumed that it was not visible in February 2009 when both links were inspected and judged to be defect-free. The degree of corrosive attack near the origin of the crack suggests that it was present for some considerable period of time and should have been visible on the outside of the link. Whilst decreasing the 36-month internal inspection interval may be seen as one mitigating measure (which needs to be balanced against the risk of introducing damage), adopting an external visual check of the top surface in the region of the oleo attachment lugs (ie similar to the inspection described in ASL 750-32-22 Part 1) at much more frequent intervals would offer a means of detecting a crack before failure. Therefore:

Safety Recommendation 2011-072

It is recommended that the Cessna Aircraft Company amends the Maintenance Schedule for the Model 750 Citation X aircraft to include a suitably frequent external visual inspection of the MLG trailing link upper surface for cracks.

Although the above Safety Recommendation does not specify the time interval, the fact that the failure on G-CDCX occurred due to SCC, which is not necessarily cycle-related, should be recognised.

Flight data recorder documentation

Whilst the accident flight was a private flight, the aircraft is normally operated under an Air Operators Certificate under EU-OPS requirements. EU-OPS 1.160 (a) (4) (ii), requires the operator to keep a document that defines how the FDR contents is converted into engineering units. The operator did not hold such a document.

The FDR installation was part of the Type Certification (TC) of the aircraft. Enquiries with the aircraft manufacturer ultimately yielded two documents, neither controlled, that between them enabled adequate analysis of the FDR data to be performed for this event. No controlled document was available from any source to enable the accurate decode of the FDR, despite the aircraft, with FDR installation, having an EASA TC. The ability to decode the FDR is an important part of continued airworthiness and therefore FDR decode documentation should be included in the set of complete instructions for continued airworthiness provided to the owner/operator, by the holder of the type certificate, as required under EASA Part 21 requirement 21A.61. The EASA TC is based on the Federal Aviation Administration (FAA) Type Certificate. The FAA does not require FDR decode documentation as part of the TC process. Both the UK Civil Aviation Authority (CAA) and the FAA have published guidance material on what information these documents should contain, under CAP 731 and AC20-141B respectively. No equivalent guidance is currently available from the EASA. This highlights areas of certification that require clarification and areas that require improved compliance checking.

Other recent and ongoing AAIB investigations involving other aircraft types and at least one other aircraft manufacturer has had similar findings. The report on the accident to a Cessna Citation Sovereign, G-CJCC, on 30 September 2010 has made the following safety Recommendations to the CAA, EASA and the FAA to resolve the issues that also affected this investigation:

Safety Recommendation 2011-024

It is recommended that the Civil Aviation Authority ensure that UK operators of aircraft equipped with flight data recorders hold and maintain controlled documentation that satisfies the intent of CAP 731 and complies with the requirements of EU-OPS 1.160 (a) (4) (ii).

Safety Recommendation 2011-025

It is recommended that the Civil Aviation Authority include in their processes associated with the issuing of Air Operator Certificates a check to ensure that the operator's procedures comply with requirements of EU OPS 1.160 (a) (4) (ii).

Safety Recommendation 2011-026

It is recommended that the European Aviation Safety Agency ensures that design organisations under their jurisdiction responsible for approvals affecting Flight Data Recorder (FDR) installations, hold the documentation required for decoding the FDR data, and that the documentation is to a suitable standard and available to operators.

Safety Recommendation 2011-027

It is recommended that the European Aviation Safety Agency review their certification requirements, guidance and procedures to ensure that controlled documentation, sufficient to satisfy operator flight data recorder documentation requirements, are explicitly part of the type certification and supplemental type certification processes where flight data recorder installations are involved.

Safety Recommendation 2011-028

It is recommended that the Federal Aviation Administration ensure that controlled documentation, sufficient to satisfy operator flight data recorder documentation requirements, is part of the type certification and supplemental type certification processes where flight data recorder installations are involved.

Safety Recommendation 2011-029

It is recommended that the European Aviation Safety Agency provides guidance detailing the standards for the flight data recorder documentation required for the certification of systems or system changes associated with flight data recorders.

Safety Recommendation 2011-030

It is recommended that Cessna Aircraft Company issue controlled documents, applicable to Cessna aircraft equipped with flight data recorders, that satisfy the EU-OPS 1.160 (a) (4) (ii) requirement, and make them available to all operators of the applicable aircraft. Furthermore, it is recommended that the documentation issued should follow the guidance given in Federal Aviation Administration document AC 20-141B and UK Civil Aviation Authority document CAP 731.