

ACCIDENT

Aircraft Type and Registration:	Jetstream 3102 31, G-GAVA
No & Type of Engines:	2 Garrett Airesearch TPE331-10UGR-516H turboprop engines
Year of Manufacture:	1987 (Serial no: 785)
Date & Time (UTC):	15 August 2014 at 1836 hrs
Location:	Doncaster Sheffield Airport, Yorkshire
Type of Flight:	Commercial Air Transport (Passenger)
Persons on Board:	Crew - 2 Passengers - 1
Injuries:	Crew - None Passengers - None
Nature of Damage:	Left main landing gear, left propeller, fuselage and wing
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	54 years
Commander's Flying Experience:	8,740 hours (of which 3,263 were on type) Last 90 days - 147 hours Last 28 days - 60 hours
Information Source:	AAIB Field Investigation

Synopsis

The aircraft's left main landing gear failed shortly after it landed on Runway 20 at Doncaster Sheffield Airport. The left main landing gear detached from its mounts and the aircraft slid along the runway on its remaining landing gear, left wingtip and baggage pannier, before veering off the runway and coming to rest on the adjacent grass. The single passenger and the flight crew vacated the aircraft without injury. The failure occurred as a result of stress corrosion cracking in the forward pintle housing, at the top of the left landing gear cylinder.

The same aircraft, operating under a different registration, was involved in a similar accident in 2012¹ during which the right main landing gear failed in the same location, also due to stress corrosion cracking.

This investigation determined that a design solution implemented by the aircraft manufacturer following the 2012 accident, which introduced a protective washer on the forward pintle housing, had not met its original design intent. A fouling condition, not identified when the design solution was first implemented, caused rotational movement of the protective washer on G-GAVA resulting in degradation of the surface protection on the forward pintle

Footnote

¹ G-CCPW at Isle of Man Airport on 8 March 2012, report EW/C2012/03/03, published in AAIB Bulletin 10/2012.

housing. This created conditions conducive to the formation of corrosion pits, from which a stress corrosion crack initiated and propagated to failure.

This report follows publication of AAIB Special Bulletin S5/2014, in which two Safety Recommendations were made. One additional Safety Recommendation is made.

History of the flight

G-GAVA took off from Belfast City Airport at 1745 hrs operating a scheduled air service to Doncaster Sheffield Airport with one passenger and a crew of two pilots on board. The commander was the Pilot Flying (PF) and the co-pilot was the Pilot Monitoring (PM).

The departure, cruise and approach to Doncaster Sheffield were uneventful. The 1820 hrs ATIS for the airport stated that the wind was from 260° at 5 kt, varying between 220° and 280°. Visibility was greater than 10 km, there were few clouds at 3,000 ft aal, the temperature was 17°C and the QNH was 1,019 hPa. Although Runway 02 was the active runway, the crew requested radar vectors for a visual final approach to Runway 20, a request which was approved by ATC. The loadsheet recorded that the aircraft's mass at landing was expected to be 5,059 kg which required a target threshold indicated airspeed (IAS) of 101 kt.

The aircraft touched down at 1836 hrs with an IAS of 102 kt and a peak normal acceleration of 1.3 g, and the commander moved the power levers aft to `GROUND IDLE` and then to `REVERSE`. As the aircraft decelerated, the commander moved the power levers forward to `GROUND IDLE` and asked the co-pilot to move the RPM levers to `TAXI`. At an IAS of 65 kt, eight seconds after touchdown, the left wing dropped suddenly, the aircraft began to yaw to the left and the commander was unable to maintain directional control with either the rudder or the nosewheel steering tiller. The aircraft ran off the left side of the runway and stopped on the grass having turned through approximately 90°. The left landing gear had collapsed and the aircraft had come to a halt resting on its baggage pannier, right landing gear and left wing (Figure 1).



Figure 1

The aircraft as it came to rest

The commander pulled both feather levers, to ensure that both engines were shut down, and switched the Electrics Master switch to EMERGENCY OFF. The co-pilot transmitted "TOWER.....[CALLSIGN]" and the controller replied "[CALLSIGN] COPIED, EMERGENCY SERVICES ON THEIR WAY". The commander instructed the co-pilot to evacuate the aircraft. The co-pilot moved into the main cabin where he found that the passenger appeared to be uninjured. He considered evacuating the aircraft through the emergency exit on the right side but judged that the main exit on the left side at the rear of the cabin would be the best option. The left side cabin door released normally but would not open completely because the sill of the doorway was at ground level (Figure 1) but, all occupants were able to evacuate the aircraft.

The Aerodrome Controller in the ATC tower activated the Crash Alarm at 1836 hrs while the aircraft was still on the paved surface of the runway. Two Rescue and Fire Fighting Service vehicles arrived on scene at 1838 hrs by which time the occupants were clear of the aircraft.

Recorded information

The aircraft was fitted with a 30-minute Cockpit Voice Recorder (CVR) and a Flight Data Recorder (FDR); both recorders captured the landing. The FDR recorded just over 116 hours of operation but only five parameters which were pressure altitude, heading, airspeed, normal acceleration and a VHF transmission discrete. Additionally, a Terrain Awareness and Warning System (TAWS) was installed in the aircraft recording 30 separate parameters, including aircraft rate of descent, time and pressure altitude, at a higher sampling rate than the FDR.

A review of the previous 82 landings recorded on the FDR has not identified any of concern with the highest normal acceleration at touchdown of 1.72g recorded during the 18th landing prior to the accident.

The aircraft touched down at 1835:52 hrs at an IAS of 102 kt and normal acceleration of 1.3g (Figure 2). Recorded rate of descent was approximately 245 ft/min (4 ft/sec) which was within the touchdown landing gear load limit which is defined as a rate of descent of 10 ft/sec at a maximum landing weight of 14,900 lb (6,758 kg).

While decelerating through a groundspeed of 65 kt, a normal acceleration spike was recorded, indicating the point at which the left main landing gear failed.

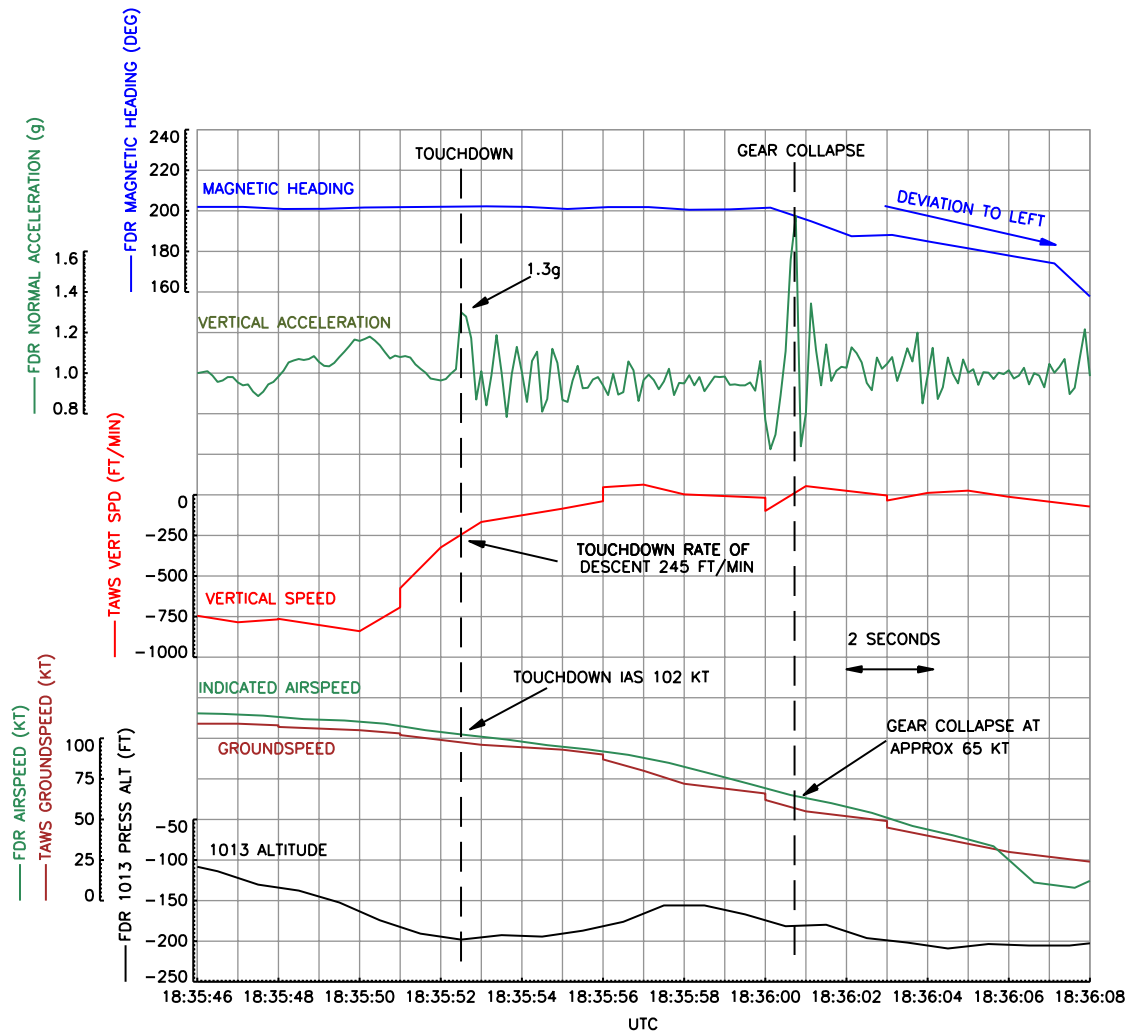


Figure 2

Flight data recorded during the landing

Runway marks

The aircraft left a number of marks on the runway, starting approximately 370 m from the start of the runway threshold markings. The first marks were made by the top of the left landing gear cylinder, after it had folded under the wing, followed immediately by the left engine propeller striking the runway surface.

Aircraft damage

The left landing gear had broken away from its mounts as a result of the failure of the forward pintle housing. Two sections of the pintle housing stayed attached to the pintle spigot (Figure 3). However, the landing gear remained attached to the aircraft by the radius arm (retraction jack) and hydraulic pipelins.

The blades on the left engine propeller had been badly damaged. The left aileron balance horn separated from the aircraft after it left the runway, becoming lodged in the soft ground. The left wingtip had sustained abrasion damage, resulting in a fuel leak from this area. The

baggage pannier and anti-collision beacon on the underside of the fuselage also sustained considerable abrasion damage.

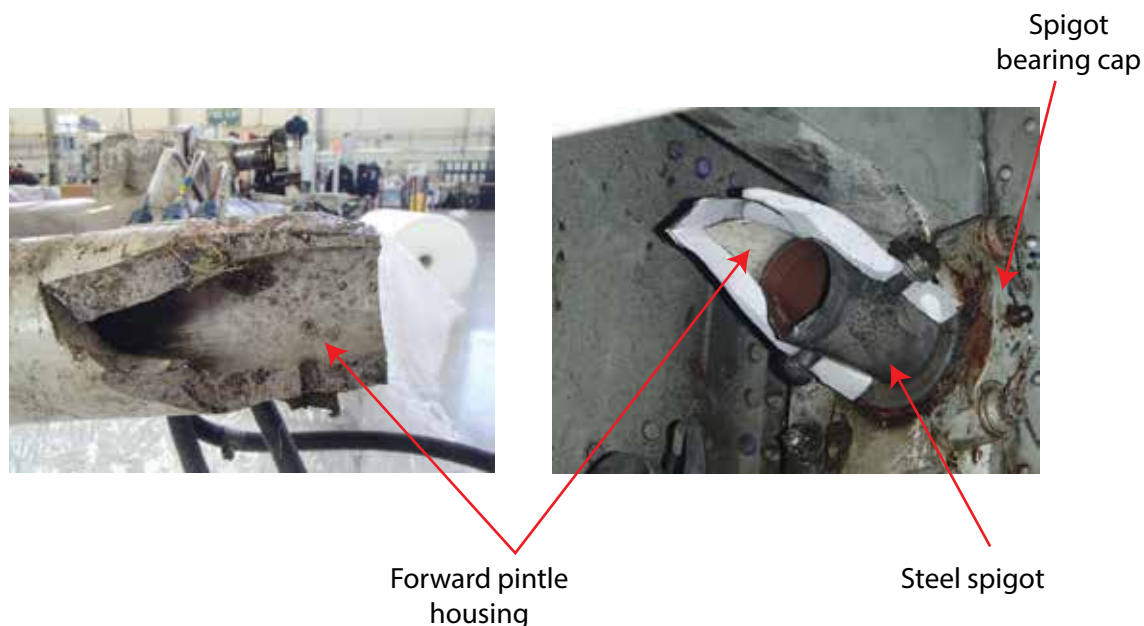


Figure 3

Left main landing gear forward pintle housing

Landing gear

The Jetstream 31 main landing gear leg consists of a cylinder, manufactured from DTD 5094 aluminium alloy, and an inner sliding tube on which the single wheel and brake assembly are mounted. The landing gear cylinder is attached to the airframe by a yoke which fits onto steel spigots, which are bolted through the pintle housings. The upper surfaces on the forward and rear pintle housings are machined flat to introduce a weak link which will fail, allowing the landing gear to detach from the airframe without damaging the fuel tanks, if it is subjected to a force outside its design limits. During the accident, the forward pintle housing failed along the machined flat (Figure 4).

The DTD 5094 landing gear cylinder is known to be susceptible to stress corrosion cracking (SCC) and similar landing gear failures have occurred on other Jetstream 31 aircraft. In particular, SCC has occurred in the forward pintle housing as a result of the forward face rotating against the spigot bearing during extension and retraction of the landing gear. The resulting abrasion causes degradation of the protective surface treatment, the consequent formation of corrosion pits and, ultimately, cracking. The Jetstream 32 main landing gear cylinder and later versions of the Jetstream 31 main landing gear cylinder are manufactured from L161 alloy and are not susceptible to SCC.

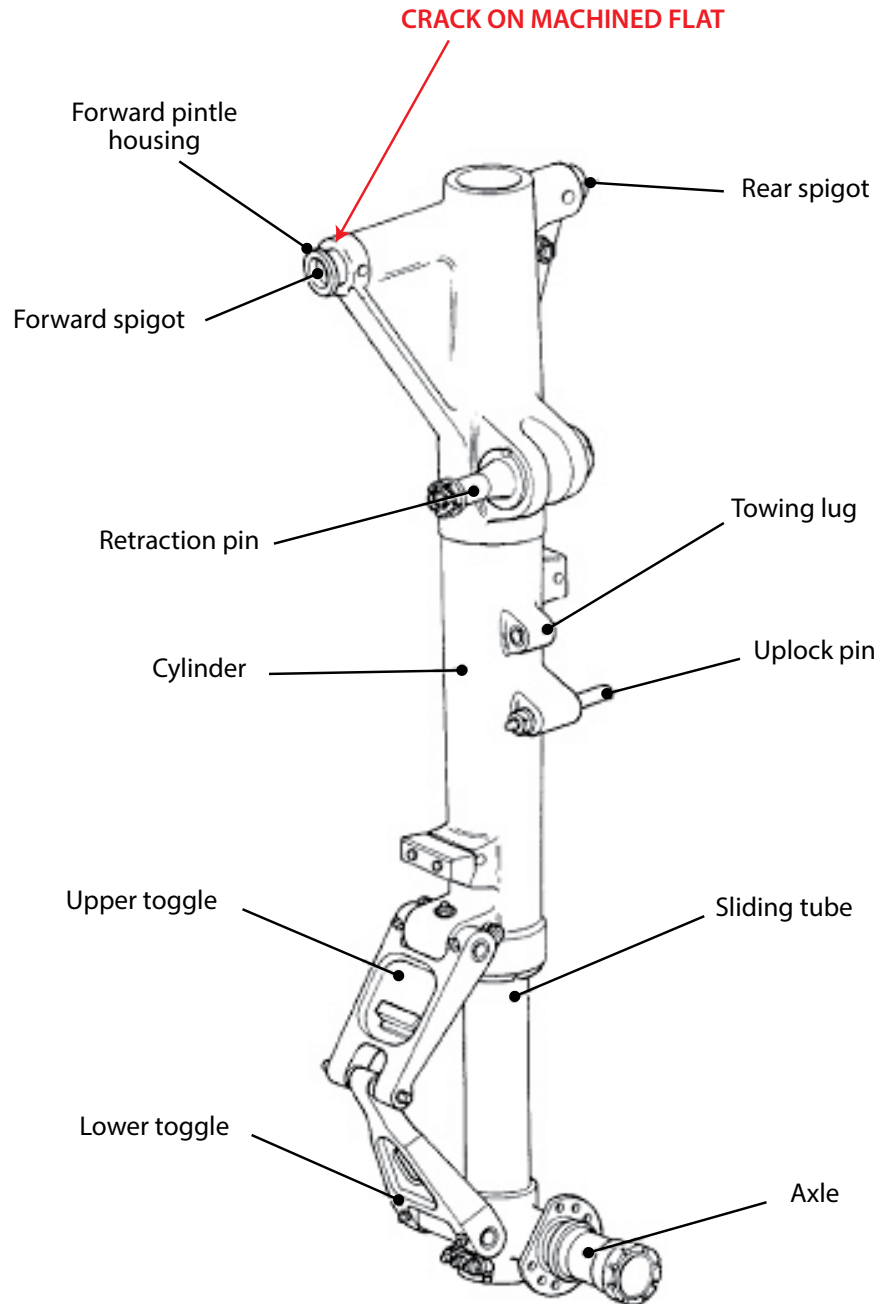


Figure 4
Jetstream 31 main landing gear leg

Previous occurrence

On 8 March 2012, the same aircraft, operating under its previous registration G-CCPW, suffered a failure to its right main landing gear as it landed at Isle of Man Airport. The subsequent investigation identified intergranular corrosion / stress corrosion cracking of the forward pintle housing as the cause of the failure and a Safety Recommendation was made to address this issue.

Stress corrosion cracking

Stress corrosion cracking can occur when susceptible metals or alloys are subject to a continuing tensile stress above a threshold level in a corrosive environment. Initiation normally occurs when the protective surface finish has been compromised allowing corrosion to start. Unless the stress is relieved or the corrosive environment is removed, the crack will continue to grow over time, travelling along the material's grain boundaries until it reaches the critical crack length, when the remaining metal will fail in sudden overload.

The issue of SCC in the Jetstream 31 main landing gear cylinder forward pintle housing was first identified in 1985 and the AAIB report into the 2012 G-CCPW accident documents the history of the problem. At the time of the G-CCPW accident, UK CAA Airworthiness Directive (AD) G-003-01-86 and BAE Systems mandatory Service Bulletin (SB) 32-A-JA851226, Revision 4 were in force, and required regular high-frequency eddy current (HFEC) and visual inspections of this area. The visual and HFEC inspections were described in Heroux-Devtek² SB 32-19, Revision 3, which was called up in SB 32-A-JA851226. The visual inspection of the forward and rear machined flats on the top of the pintle housing was required to be performed with the landing gear in-situ, every 300 cycles or three calendar months, whichever occurred sooner. The HFEC inspection of the machined flats and the forward and rear faces of the pintle housing was required to be performed with the landing gear removed, every 1,200 cycles or one calendar year.

The G-CCPW investigation determined that the HFEC and visual inspections had not been successful in detecting the presence of cracks before failure occurred. In particular, the report raised concerns about the limitations of the HFEC technique in detecting cracks in the forward pintle housing caused by SCC, due to edge effects, minimum detectable crack length and sensitivity of the technique in the presence of corrosion. Previous work done by BAE Systems in response to stress corrosion cracking events in the 1980s, and documented in the G-CCPW AAIB report, established that a minimum crack length of 1.57 mm was required to initiate steady crack growth. Once the crack had reached 1.57 mm it could then grow steadily to 6 mm over a period of approximately 120 days, at which point the crack length would become critical and could fail in overload. The HFEC technique described in SB 32-A-JA851226 Revision 4 and SB 32-19 Revision 3 was capable of detecting cracks of approximately 2.03 – 2.54 mm.

As a result, the G-CCPW investigation made the following Safety Recommendation on 23 March 2012:

Safety Recommendation 2012-008

It is recommended that the European Aviation Safety Agency review the effectiveness of Airworthiness Directive G-003-01-86 in identifying cracks in the yoke pintle housing on landing gears fitted to Jetstream 31 aircraft.

Footnote

² Heroux-Devtek, formally known as APPH, the landing gear Type Certificate holder.

Safety actions arising from G-CCPW accident

Responding to Safety Recommendation 2012-008 on 19 June 2012, the European Aviation Safety Agency (EASA) indicated their intention to undertake a review of AD G-003-01-86 and SB 32-A-JA851226, in conjunction with the aircraft manufacturer. EASA stated:

'It is agreed that the current service bulletin is not adequate and it is under the process of revision. A revised service bulletin will be produced which will be mandated by an Airworthiness Directive.'

Based on this response the AAIB categorised the status of this Safety Recommendation as 'Accepted – Closed'. Subsequently SB 32-A-JA851226 was updated to Revision 6, published on 18 December 2013, and this was mandated by EASA AD 2013-0208³, which superseded UK CAAAD G-003-01-86. SB 32-19 was also updated to Revision 6, published on 02 December 2013. The changes to SB 32-A-JA851226 and SB 32-19 included revised access instructions, revised instructions for re-protecting the forward pintle housing after the HFEC inspection and various administrative updates. However, there were no changes to the HFEC technique, equipment or inspection intervals.

As BAE Systems concluded that the HFEC inspection technique may have been of limited effectiveness in identifying SCC, because the estimated critical crack size is small and the rate of crack growth can be rapid, following the G-CCPW event, BAE Systems decided to place increased emphasis on prevention rather than detection of SCC. As such, they published modification service bulletin SB 32-JM7862, dated May 2013, to introduce a new design solution. This SB, which was mandated by EASA AD 2013-0206, dated 9 September 2013, required installation of a 'special' washer to protect the forward face of the pintle housing from rubbing against the spigot bearing during landing gear extension and retraction and therefore prevent the initiation of SCC. A new bearing with a reduced-thickness flange was also introduced to accommodate the washer. SB 32-JM7862 required an anaerobically-curing⁴, low-adhesion, liquid gasket to be applied to the washer's contact surfaces, the primary purpose of which is to keep moisture out. A pre-formed 90° rectangular tab on the washer was designed to fit flush against the machined flat on top of the pintle housing to lock the washer in position and prevent rotation. The tab included an 'inspection window' to facilitate the routine visual inspections of the machined flat without the need to remove the landing gear. SB 32-JM7862 was applicable to all Jetstream 31 and 32 aircraft in order to maintain commonality, although different compliance times were specified for L161 landing gear cylinders.

In April 2014, while embodying SB 32-JM7862, a Jetstream 31 operator reported a possible integration issue to BAE Systems, where the bearing locking pins in the spigot bearing cap protruded through the bearing flange and fouled against the special washer, preventing reinstallation of the landing gear. As a consequence, BAE Systems issued Revision 2 of SB 32-JM7862 on 13 June 2014, with an instruction to transpose the spigot bearing

Footnote

³ EASA AD2013-0208 mandated Revision 5 of SB 32-A-JA851226. However Revision 5 was not issued to operators but was revised to Revision 6 prior to release.

⁴ An anaerobic adhesive, in this case the gasket material, will not cure in the presence of air.

cap by 180° so that the bearing locking pins did not come into contact with the washer. The compliance instructions for aircraft which already had SB 32-JM7862 embodied at Revision 1, were to reverse the orientation of the spigot bearing cap '*at the next convenient maintenance input (e.g. when the aircraft is jacked)*'.

Initial examination of landing gears

Post-accident examination of G-GAVA's left landing gear identified that the special washer was in approximately the correct position, although the rectangular tab was bent up at a slight angle at one edge, rather than lying flush against the machined flat of the forward pintle housing. The special washer on the right landing gear had rotated out of position in an inboard direction. Prior to this accident BAE Systems had not received any reports relating to rotation of the special washers introduced by SB 32-JM7862.

Metallurgical examination of left landing gear

General

Metallurgical examination of the forward pintle housing on G-GAVA's left main landing gear was carried out by QinetiQ, under the direction of the AAIB. This examination determined that the failure initiated from a corrosion pit on the forward face of the pintle housing. The resulting crack propagated axially along the top of the pintle housing, which then finally failed in overload.

Axial crack through pintle housing

The axial crack propagated aft for 74 mm, before extending a further 76 mm in a downwards and outboard direction (Figure 5).

Both fracture surfaces of the axial crack had a 'woody' appearance, characteristic of SCC. Smearred gasket material was present on the top of the fracture surfaces, towards the start of the crack. Examination of the inboard fracture surface showed that corrosion was present within the first 35 mm, extending rearwards and downwards. A narrow band of corrosion along the top of the fracture surface extended for a further 40 mm. Figure 6 shows the corrosion staining in the area bounded by the dashed red line.

Scanning electron microscopy of the fracture faces, showed a small flat fracture region, measuring 2.4 mm x 1.5 mm, extending from a corrosion pit on the forward face of the pintle housing, close to the top surface. Within this flat fracture region, the surface showed extensive corrosion and the crack growth appeared intergranular, typical of SCC. Beyond the flat fracture region, the corrosion staining was less severe but the fracture surface was still intergranular in nature. Approximately 14 mm from the crack origin, ductile features start to become evident in the corrosion-stained area. The remainder of the fracture surface within the corrosion-stained region exhibited a combination of intergranular features and ductile dimples, with ductile features becoming more prevalent and corrosion less severe as the crack progressed. Although DTD 5094 fracture surfaces are difficult to interpret, the prevalence of ductile features on some areas of the fracture surface suggests that overload failure also contributed to the later stages of the axial

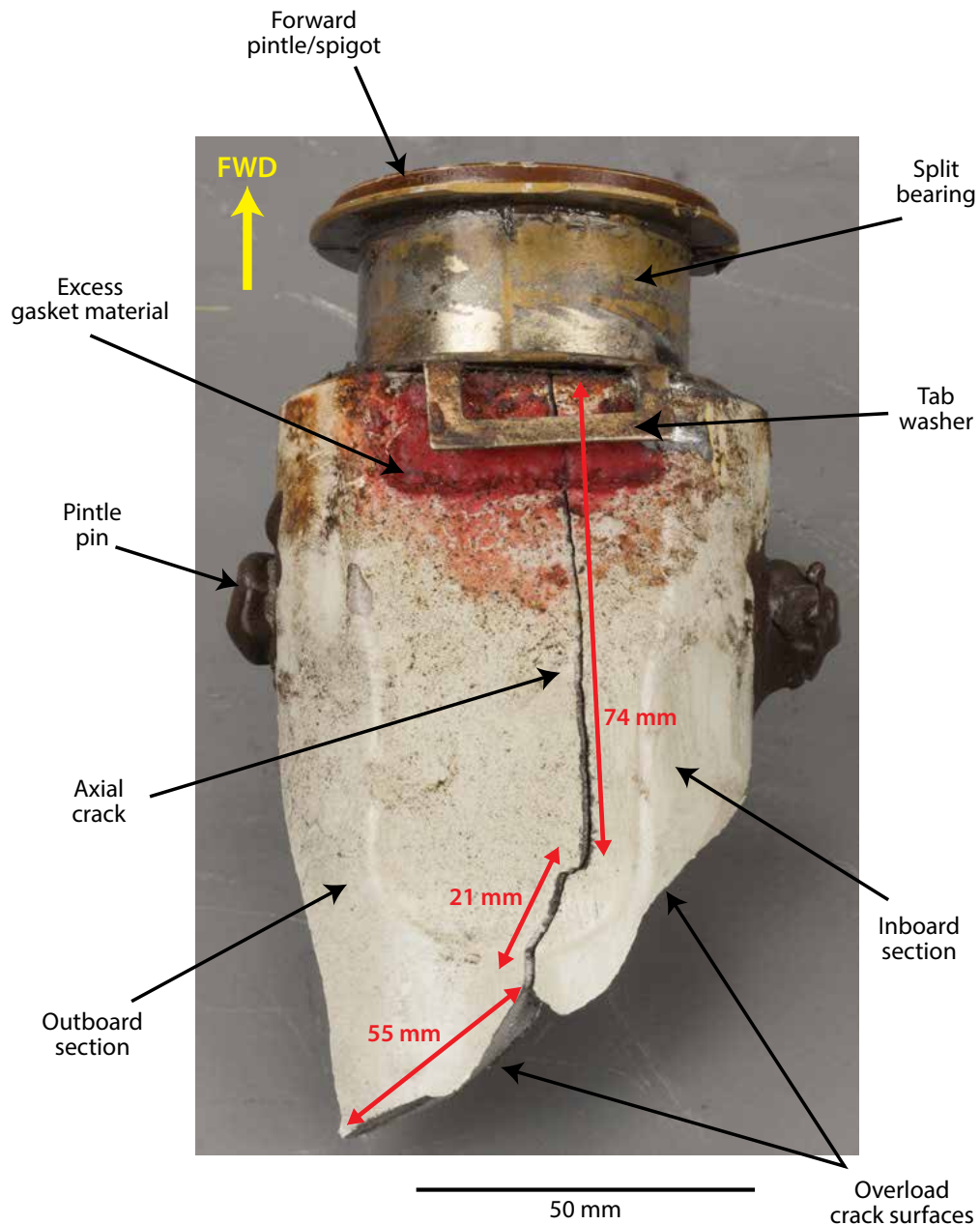


Figure 5

Left landing gear forward pintle housing showing crack

crack progression. The severity and depth of the corrosion staining towards the start of the crack suggest that this part of axial crack had been open for some time prior to final failure, although it was not possible from the metallurgical analysis to determine for what length of time the crack may have been present. The reduced severity and depth of the corrosion band in the later stages of the axial crack suggest that this part of the crack was open for a shorter period of time.

Energy dispersive x-ray spectroscopy (EDX) analysis identified the presence of oxygen, suggesting oxidation (corrosion) of the surface, as well as cadmium, which is likely to

have come from corrosion of the steel spigot. Chlorine, which is known to cause SCC in aluminium alloys and is normally present in marine environments, was also detected in the corrosion product.

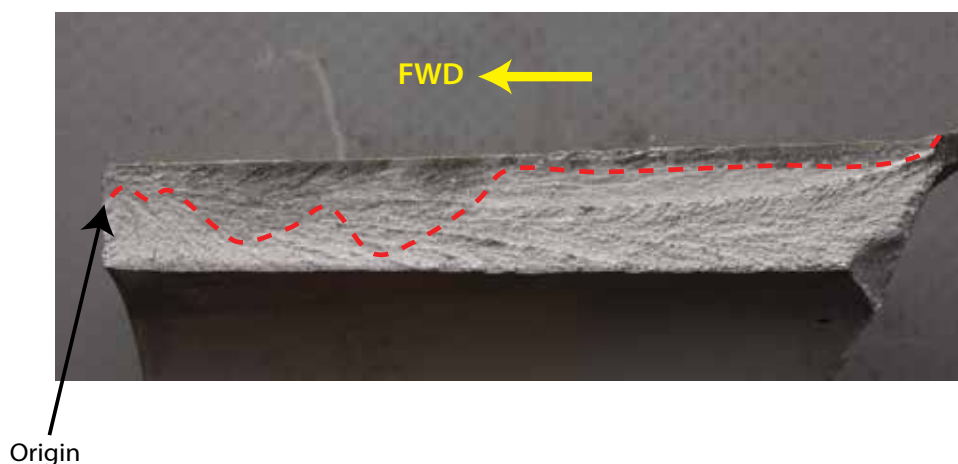


Figure 6

Left landing gear, inboard half of axial crack fracture surface after cleaning, showing corrosion staining

Forward face of the pintle housing and special washer

The forward face of the pintle housing exhibited rotational wear marks where the Alochrome surface treatment was worn off and corresponding wear marks were evident on the mating face of the special washer. One witness mark on the washer aligned with the position of the axial crack.

Corrosion pitting was evident on the forward face of the pintle housing. A polished micro-section through the forward face showed that some of the pits extended to a depth of 180 μm , and intergranular cracks were evident adjacent to the pits suggesting other possible crack initiation sites. No gasket material was visible on the forward face of the pintle housing or the mating face of the washer. However, the Loctite 5203 gasket material fluoresces under UV light, and using this technique, two tiny fragments of gasket material were identified, indicating that gasket material had previously been present.

The smeared gasket material on the machined flat, on the top surface of the pintle housing, visible in Figure 5, did not fluoresce under UV light and its consistency confirmed that it had only partially cured. After removing this gasket material from the machined flat, it was noted that the paint in this area was blistered.

Washer and bearing locking pins

The washer tab was distorted and rotational wear marks were evident on the forward face of the washer, around the inboard edge. This wear is consistent with contact between the washer and the bearing locking pins in the spigot bearing cap. Substantial wear was evident on the bearing locking pins, including a distinctive notch on each pin, created by the outer edge of the washer (Figure 7). The top and bottom pins protruded 1.95 mm

and 2.03mm respectively, from the surface of the spigot bearing cap. The bearing flange measured 1.64 mm thick.

A witness mark on the forward face of the washer corresponding to the gap between the split bearing halves indicated the washer's normal position; a similar witness mark displaced by 40° indicated the extent to which the washer was able to rotate out of position.

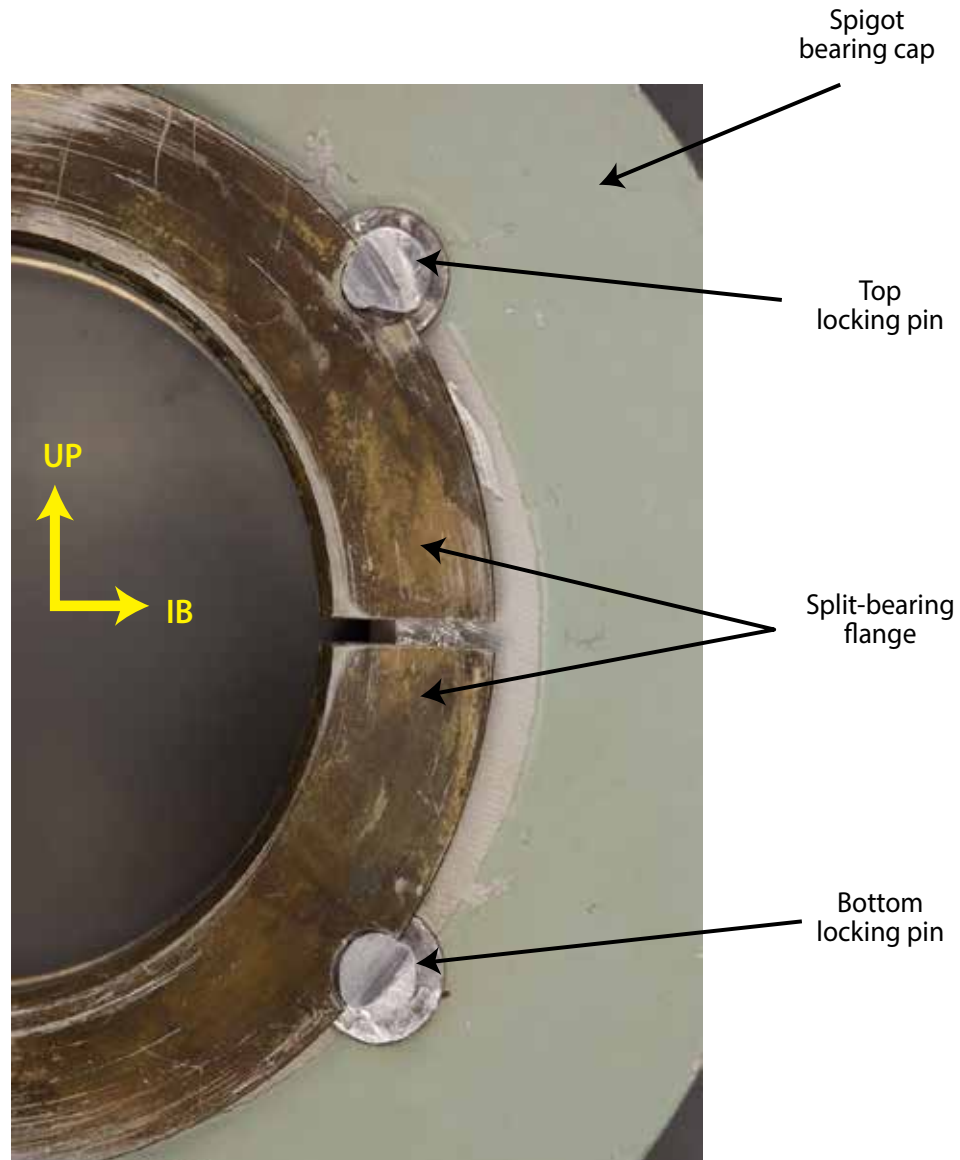


Figure 7

Left landing gear, wear on bearing locking pins

Pintle housing bore

Corrosion pitting was present in the bore of the pintle housing, heavily concentrated towards the forward end and gradually decreasing towards the rear. Corresponding dark staining, characteristic of galvanic corrosion, was also present on the steel spigot, most likely as a result of interaction between the spigot and the aluminium pintle bore. Although the

corrosion in the bore did not contribute to the failure of the pintle housing, corrosion in this area is undesirable and was the subject of Safety Recommendation 2012-024, arising from the G-CCPW investigation.

Overload cracks through the pintle housing

The final overload failure of the pintle housing initiated at the internal edges of both pintle pin holes, close to the bore, with separate cracks propagating forward and aft. The fracture surfaces through the holes appeared dull and fibrous, characteristic of overload failure. The crack surfaces from the pintle pin holes to the end of the axial crack were relatively clean, suggesting they were the last parts of the pintle housing to crack, most likely during the final landing immediately prior to the landing gear collapse.

Eddy current examination

As part of the landing gear examination, a HFEC inspection was performed on the forward face of the three broken sections of the pintle housing, using the technique called up in SB 32-A-JA851226, Revision 6 and SB 32-19 Revision 6. The examination did not identify any defect indications. However, parts of the forward face were missing and other areas had suffered mechanical damage during the accident, which may have obscured any defects in those areas.

Detailed examination of right landing gear

G-GAVA's right main landing gear cylinder had been subject to the same overhaul and recent component history as the failed left gear. Additionally, post-accident inspection showed that the special washer on the right landing gear had rotated out of position. Therefore a detailed examination of the forward pintle housing on the right landing gear cylinder was conducted for comparative purposes.

The special washer had rotated such that its tab had passed the inboard corner of the machined flat on the pintle housing. Correctly cured gasket material was evident on the machined flat, under the footprint of the washer tab, but the gasket was absent from the forward face of the pintle housing, except for one small fragment. This fragment had collected in a small depression on the surface, which had the appearance of a blend, possibly indicating the site of a previous repair on the cylinder, although no such repair was referenced in the component records. Rotational wear patterns and witness marks on the forward face of the pintle housing and both faces of the washer, and wear on the bearing locking pins were very similar to those on the left landing gear and indicated that the washer had rotated up to 53° from its normal position.

There was extensive corrosion pitting on the forward face of the pintle housing, most prevalent around the bore, with crack-like features appearing to emanate from the corrosion pits. A HFEC inspection using the technique called up in SB 32-A-JA851226, Revision 6 and SB 32-19 Revision 6, identified defect indications which exceeded the maximum permissible limit. A dye-penetrant inspection was conducted to highlight these defects; the results are shown in Figure 8. The damage was determined to be outside permissible repair limits and the right landing gear cylinder was deemed to be 'scrapped'.

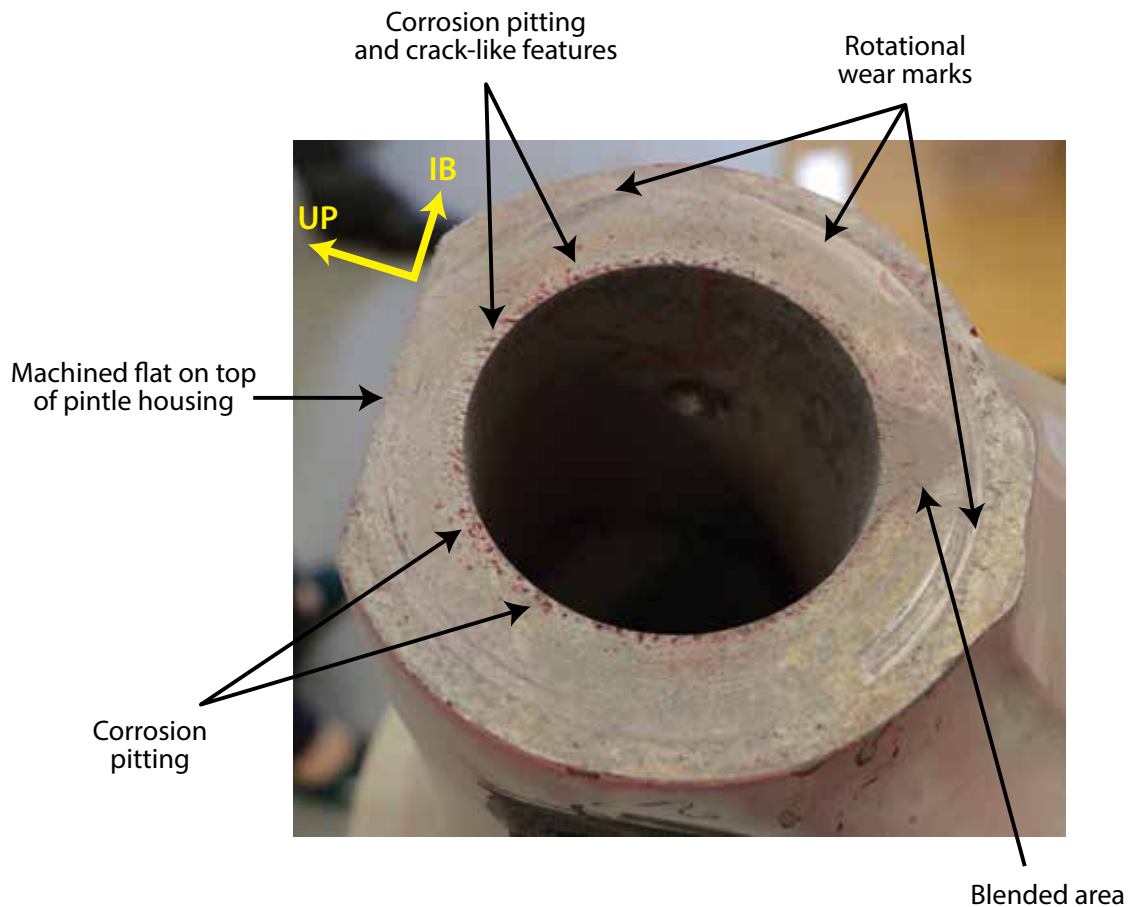


Figure 8

Right landing gear, forward face of pintle housing after dye penetrant examination

Gasket curing trial

The curing performance of the Loctite 5203 liquid gasket material on the landing gear cylinder was assessed. Liquid gasket material applied on the painted surface of the machined flat did not cure after 24 hours at room temperature because one surface of the gasket was exposed to the air. Liquid gasket was also used to install a special washer on the pintle housing, in accordance with the SB 32-JM7862 instructions, and was subject to the same cure time and temperature. The gasket adequately cured on the forward face but only partially cured under the washer tab. The investigation considered that the gap between the washer tab and the pintle surface may have been too large to allow full anaerobic curing of the gasket. The gasket material had also softened the top coat of paint on the machined flat of the pintle housing.

Design tolerances

Following the G-GAVA accident, BAE Systems conducted an assessment of the modification described in SB 32-JM7862 Revision 1, to understand how fouling could occur between the bearing locking pins and the special washer. Each locking pin engages in a cut-out on the split bearing flange, ensuring that both halves of the bearing remain in position. The spigot bearing cap can be installed either with the bearing locking pins facing aft towards

the special washer (as was the case on G-GAVA) or, with the bearing locking pins facing forward so that they engage with the opposite bearing flange, where no fouling condition would exist. Post-accident assessment determined that, with the bearing locking pins facing aft, a foul of up to 0.022 in (0.559 mm) could occur on some aircraft as a result of adverse tolerances. However, on aircraft with more favourable tolerances, a small clearance of up to 0.005 in (0.127 mm) might exist between the bearing locking pins and the washer. The written instructions in SB 32-JM7862 Revision 1 did not specify a particular orientation for the spigot bearing cap, although Figure 1 of the SB showed the bearing locking pins facing aft towards the special washer, as did the relevant Aircraft Maintenance Manual (AMM) instructions for reinstalling the landing gear.

Maintenance history

General

Jetstream 31 landing gears are required to be overhauled every 10,000 cycles or six calendar years and both main landing gears were overhauled in December 2012 and fitted to G-GAVA later that month⁵. The aircraft returned to service in April 2013. At the time of the accident in August 2014, both landing gears had accumulated 955 cycles since overhaul.

Routine line and base maintenance of the operator's aircraft was provided by a maintenance organisation at Humberside Airport, which was a wholly-owned subsidiary of the operator. Ad hoc maintenance and larger maintenance checks were carried out by a third-party maintenance organisation based at Cranfield Airport.

Third-party maintenance

The most recent HFEC inspection for stress corrosion cracking on the pintle housing was performed on both landing gears by a specialist Non-Destructive Testing (NDT) company on 10 December 2013, 803 cycles prior to the accident, during a 200 hr check at the third-party maintenance organisation. No defects were detected. SB-32-JM-7862 Revision 1 was embodied on both landing gears to install the protective washer on the forward pintle housing on 12 December 2013 during the same maintenance input.

During a subsequent 1200 hr maintenance input at the third-party maintenance organisation in March 2014, while performing a detailed visual inspection (DVI) of the landing gear, the protective washers on both landing gears were observed to have rotated out of position. The DVI also identified extensive corrosion and encrusted salt contamination in both main landing gear bays, on a number of hydraulic connectors, and the radius rod attachment pins and nuts.

The senior engineer who certified the work performed on G-GAVA during the December 2013 and March 2014 maintenance inputs, informed the investigation that he had been surprised at the extent of the deterioration in the landing gear bays in the intervening three months. He also noted an absence of lubrication on the landing gears, despite them having been

Footnote

⁵ Both landing gears were overhauled at a dedicated overhaul facility in the USA and carried different serial numbers from those that were fitted to G-CCPW at the time of the previous accident.

lubricated in December 2013. The operator was informed of the findings and advised the maintenance organisation that the aircraft had operated to a number of coastal locations and had spent a lot of time on the ground in the preceding months, due to adverse winter weather.

Upon removing both landing gears to rectify the migrated washers, circular wear patterns were observed on the forward face of the pintle housings where the washers had rotated, but there was no visible corrosion. The forward face of the pintles was cleaned and the surface protection reapplied prior to reinstallation of the washers. Neither the third-party maintenance organisation nor the operator informed the aircraft manufacturer that the protective washers had rotated out of position.

The senior engineer informed the investigation that during both the original embodiment of SB 32-JM7862 and the subsequent reinstallation of the washer, some difficulty had been experienced achieving an adequate cure on the liquid gasket and getting the washer tab to sit flush against the top of the pintle housing. On both occasions a heat gun had been used to accelerate the cure. He expressed some concern that SB 32-JM7862 did not provide a definitive procedure for achieving an accelerated cure of the gasket, nor a means to determine when the gasket had fully cured. Instead maintenance personnel must assume the gasket has started to cure once the washer is secure. The third-party maintenance organisation did not report these observations to the aircraft manufacturer.

The senior engineer was aware of the importance of the inspection window in the washer tab and was certain that the excess gasket material (visible in Figure 5) had not been present when G-GAVA left the third-party maintenance facility in March 2014. Another aircraft on which the third-party maintenance organisation had embodied SB 32-JM7862 was inspected by the AAIB and no anomalies were noted; the washer was in the correct position, with the tab secure and flush against the machined flat, and no excess gasket material was visible.

In-house maintenance

The aircraft's technical records indicated that three visual inspections for stress corrosion cracking, as required by SB 32-A-JA851226, had been performed between reinstallation of the special washer in March 2014 and the accident on 15 August 2014. The most recent of these inspections was on 30 June 2014, 168 cycles⁶ before the accident and prior to that, on 15 June 2014 during a 200 hr check. The records indicated that both of these inspections were performed and certified by the maintenance manager at the operator's maintenance organisation. No defects were recorded. The previous visual inspection had been performed on 29 April 2014.

Although aware of the requirements of the visual inspection and of the need to clean the pintle housings and use a torch and inspection mirror to facilitate the inspection, the

Footnote

⁶ AAIB Special Bulletin S5/2014 reported that this inspection occurred 226 cycles before the accident. This figure was incorrect, having been calculated from a printed work-card, which contained out-of-date hours and cycles information.

maintenance manager reported that the inspections were often rushed and he did not usually have time to clean the landing gears due to his workload. He also stated that he commonly conducted the 'DVI described in the AMM' rather than referring to the specific visual inspection described in SB 32-A-JA851226.

The DVI inspection detailed in the AMM is required to be completed every 400 hours and describes a visual inspection of the pintle housings. It states:

'Areas to be inspected must be clean and clear of grease..... Using a good light source, a magnifying glass and mirror, do a thorough visual inspection of [the] pintle housing for signs of cracks and corrosion damage.'

While similar to the visual inspection described in SB 32-A-JA851226, unlike SB 32-A-JA851226 it does not specifically refer to the machined flat at the top of the pintle housing, or contain any illustrations showing the specific location in which the inspections should be performed.

The last maintenance performed on the landing gears was a scheduled DVI, which was conducted during a 200 / 400 hr check on 10 August 2014, 5 days before the accident. No findings were recorded. The work-pack also included a task to lubricate both landing gears, including the split bearings on the spigots.

The maintenance manager had commenced employment with the maintenance organisation in late January 2014, having been recruited to manage a small team of engineers responsible for carrying out unscheduled and line maintenance (up to 400 hr checks) for the operator's fleet. At that time he was the only permanently-employed, type-rated, B1⁷ licensed engineer working on the operator's aircraft, although he was assisted by an unlicensed engineer, a B2⁸ licensed engineer and, on occasion, by licensed and unlicensed contract engineers. He did not consider that the maintenance organisation was sufficiently resourced to fulfil the maintenance requirements of the operator's fleet and reported that he was routinely behind with performing maintenance tasks and signing off the associated maintenance paperwork. He advised the investigation that he did not believe the operator allocated sufficient aircraft down-time for maintenance inputs and he often released aircraft to service in advance of the maintenance paperwork having been reviewed and certified. The maintenance manager left the company a number of weeks after the G-GAVA accident.

In late April 2014 another licensed but non type-rated engineer was employed to assist the maintenance manager. However, his employment coincided with a long-term sickness absence of the operator's Continuing Airworthiness Manager, during which time the operator's technical records had become considerably out of date. As a consequence, the licensed engineer was soon diverted to fulfil this role instead. He received some limited training on the technical records software and spent a number of months learning to use

Footnote

⁷ An aircraft engineer with an EASA Part 66 B1 category licence (mechanical, airframe and engines), with an appropriate type rating, can certify work on an aircraft's airframe and engines.

⁸ An aircraft engineer with an EASA Part 66 B2 category licence (avionics), with an appropriate type rating, can certify work on an aircraft's avionics systems.

the technical records system, preparing work-packs for upcoming maintenance checks, entering the details of maintenance tasks, while attempting to update the historical technical records retrospectively.

The out-of-date technical records had an adverse impact on the forecasting of maintenance tasks for the operator's aircraft. A number of maintenance tasks became overdue and some tasks were erroneously scheduled. The later effect was evidenced by the close scheduling of the two visual inspections on G-GAVA on 15 and 30 June 2014, despite the required three-month interval. In particular, the printed work cards for these two visual inspections recorded the same date (29 April 2014) for the previous satisfactory visual inspection, confirming that the operator's technical records database had not been updated in the intervening period. Despite the anomalies with the maintenance forecasting, the investigation determined that the visual inspection on G-GAVA had not been overdue at the time of the accident.

CAA oversight

The operator held an EASA Part M 'Continuing Airworthiness Requirements' approval and the operator's maintenance organisation held an EASA Part 145 'Maintenance Organisation' approval⁹. The CAA was responsible for providing oversight of these functions and carrying out routine audits. The maintenance organisation was a wholly-owned subsidiary of the operator and shared the same Accountable Manager¹⁰.

In early January 2014 the CAA attempted to carry out an audit of the Part 145 and Part M functions, but the audit was terminated early due to the number of issues noted on the Part 145 side. These included concerns with the hangar facilities, inadequate engineering stores provision and inadequate training and competency records for engineering staff and contractors. As the audit was terminated early no formal audit findings were raised. However the CAA's concerns were communicated to the Accountable Manager and the maintenance organisation was given ten days to provide a corrective action plan detailing how they intended to re-establish compliance. The CAA were satisfied with the proposed plan and over the following months they maintained a dialogue with the Accountable Manager to monitor progress. The maintenance organisation appointed a new maintenance manager and part-time quality manager and work commenced to re-establish compliance with the Part 145 requirements. The CAA was satisfied that things were moving in the right direction.

Footnote

⁹ European Regulation EC 2042/2003 (and its subsequent amendments) were valid at the time of the accident and detailed the rules for the continuing airworthiness and maintenance of aircraft subject to EASA regulation. Part 145 of the regulation concerned the maintenance of EASA aircraft used for commercial air transport. Part M, Subpart G of the regulation concerned the management of continuing airworthiness of EASA aircraft. European Regulation EC 2042/2003 was superseded by Commission Regulation (EU) No 1321/2014 on 26 November 2014.

¹⁰ Under Regulation EC 2042/2003, the 'Accountable Manager' is the designated person responsible for those organisational functions which are subject to regulation. Persons nominated for this post in UK aviation organisations must be approved by the CAA. The Accountable Manager normally has corporate authority for ensuring that all of the organisation's activities can be financed and carried out to the standard required by the Regulator.

The CAA performed a rescheduled audit of the Part M and Part 145 functions between 22 and 24 July 2014, which identified seven Level 2¹¹ findings against the Part M approval and nine Level 2 findings against the Part 145 approval.

Among the Part M findings were the following concerns:

- The Maintenance Programme being used by the operator did not reflect the latest manufacturer's requirements, nor the actual aircraft utilisation in the operator's fleet.
- The operator was unable to demonstrate to the CAA that it was fully compliant with regard to the certification of maintenance tasks.
- The CAA deemed that operator's available staff resources were insufficient to complete all the required continuing airworthiness management tasks and the organisation could not demonstrate to the CAA how it had completed internal audits or how it monitored its Part M functions.

The Part 145 audit findings included:

- The maintenance organisation was unable to demonstrate to the CAA that it was fully compliant with regard to '*certification of maintenance beyond licence privilege.*' In particular the audit noted that the maintenance manager had signed off a maintenance task which was outside the entitlement of his licence.
- The maintenance organisation could not demonstrate to the CAA how it had completed internal audits of its Part 145 functions.
- The maintenance organisation was unable to demonstrate to the CAA that it was fully compliant with regard to staff resources. In particular, the CAA deemed the available resources insufficient to support projected workload as there was only one permanent licensed certifying engineer.

The findings of the audit were verbally briefed to the Accountable Manager and the management team at both organisations at the conclusion of the audit on 24 July 2014. Prior to issuing the formal notification of audit findings, the CAA requested the operator to provide additional information. Consequently, formal notification of the audit findings was not issued until 26 August 2014.

In September 2014 the Accountable Manager submitted responses to the audit findings, but the CAA deemed that they did not adequately address the concerns identified in the audit. Therefore, at the CAA's recommendation, the maintenance organisation voluntarily

Footnote

¹¹ The CAA audit form defines a Level 2 finding as '*any non-compliance with the applicable requirements which could lower the safety standard and possibly hazard flight safety*' and a Level 1 finding as '*any significant non-compliance with the applicable requirements which lowers the safety standard and hazards seriously the flight safety.*'

suspended its Part 145 approval on 18 September 2014, contracting all Part 145 maintenance activities to a third-party maintenance organisation. Additionally, the operator contracted a number of Part M functions to the same third-party organisation, including maintaining and updating maintenance records, maintenance forecasting, production of work-packs and assessment of applicable ADs.

Safety recommendations and actions arising from this investigation

Safety recommendations

As a result of the preliminary findings of this investigation, reported in AAIB Special Bulletin S5/2014, the following Safety Recommendations were published on 2 September 2014:

Safety Recommendation 2014-038

It is recommended that the European Aviation Safety Agency take action to assure the continued airworthiness of those BAE Systems Jetstream 31 main landing gear legs that are manufactured from DTD 5094 aluminium alloy and have SB 32-JM7862 embodied.

and,

Safety Recommendation 2014-039

It is recommended that the European Aviation Safety Agency take action to mandate an effective inspection regime for the Jetstream 31 that will detect cracking and prevent failure of the yoke pintle of main landing gear legs manufactured from DTD 5094 aluminium alloy.

Response to Safety Recommendations 2014-038

In response to the preliminary findings of this investigation and to Safety Recommendation 2014-38, BAE Systems published SB 32-A-JA140940 and SB 32-JM7862 Revision 3 on 3 October 2014, to address the unsafe condition which had been identified on aircraft where SB 32-JM7862 had previously been accomplished to Revision 1 and Revision 2. SB 32-A-JA140940 has three parts:

- Part 1 requires a one-off visual inspection on all aircraft where SB 32-JM7862 was first accomplished at Revision 2, within 50 cycles or 2 weeks of the date of the SB, to determine if the special washer had migrated. If there is no evidence of migration the SB requires a small amount of witness paint to be applied between the washer tab and the machined flat on the forward pintle housing, to aid identification of any subsequent rotation of the washer.
- For any aircraft where migration of the washer was identified or suspected and, for all aircraft where SB 32-JM7862 was first accomplished at Revision 1, Part 2 of SB 32-A-JA140940 is required to be performed within 200 cycles or 2 months for DTD5094 landing gears, and 600 cycles or 6 months for

L161 landing gears. Part 2 requires removal of the landing gear and special washer, inspection of the washer and the forward pintle housing for signs of wear or corrosion and rectification of any findings, an HFEC inspection of the forward pintle housing accordance with SB 32-A-JA851226 and reapplication of the corrosion protection. Reinstallation of the special washer must be performed in accordance with the enhanced instructions of concurrently-issued SB 32-JM7862 Revision 3, which include specification of the gap size to be achieved between the washer tab and machined flat, the application of witness paint and a landing gear extension/retraction check.

- For all landing gears on which Part 1 or Part 2 of SB 32-A-JA140940 has been accomplished, Part 3 requires a one-off visual inspection to be performed between 20 and 30 cycles, or 4 and 6 weeks, to determine if the witness paint is intact.

Additionally SB 32-A-JA140940 contains instructions to report all findings from the inspections to BAE Systems, even if no faults were found, using a dedicated feedback form included in the SB. At the time of publication of this report, SB feedback forms received and targeted operator follow-up by the manufacturer, indicated that SB 32-A-JA140940 and SB 32 JM7862 Revision 3 have been embodied on approximately 76% of the operational Jetstream 31 and 32 fleet. The feedback included one report of a post-SB 32-A-JA14090/SB32-JM7862 Revision 3 installation on a JS31 aircraft, where the washer tab had lifted slightly and the witness paint had broken, although there was no evidence of washer rotation. BAE Systems requested further details and the operator advised that, following subsequent reinstallation of the washer in accordance with SB 32-JM7862 Revision 3, no further anomalies have been noted.

On 3 November 2014 EASA published AD 2014-0239, superseding AD 2013-0206, to mandate the requirements of SB 32-A-JA140940 and SB 32-JM7862 at Revision 3. The mandated compliance times differed from those recommended in SB 32-A-JA140940 as the AD publication date was one month later than that of the SB.

EASA disseminated AD 2014-0239 to other National Aviation Authorities (NAA) in countries where Jetstream 31/32s are registered. The US Federal Aviation Administration issued equivalent AD 2015-06-01, effective 24 April 2015, and other NAAs including Transport Canada and the Australian Civil Aviation Safety Authority have made AD 2014-0239 available on their website.

Based on these actions, the AAIB has categorised the status of Safety Recommendation 2014-038 as '*Adequate – Closed.*'

Response to Safety Recommendations 2014-039

In response to Safety Recommendation 2014-039, EASA provided the following interim response to the AAIB on 28 October 2014:

'EASA is working with British Aerospace (BAe) Systems to review and improve the inspection regime required by the Service Bulletin (SB) 32-A-JA851226 and mandated by the Airworthiness Directive (AD) 2013-0208. In the short term, the new SB, that is being produced to check the correct installation of the special washer and thus prevent the stress corrosion, together with the inspections of SB 32-A-JA851226 are deemed to provide an acceptable level of safety. In recognition of the on-going AAIB investigation, due consideration will be given to any and all future findings from the investigation.'

The existing HFEC inspection technique called up in SB 32-JA851226 Revision 6 can achieve a detectable crack size of approximately 0.08 – 0.1 in (2.03 – 2.54 mm). Following the G-GAVA accident, BAE Systems developed a revised HFEC inspection procedure which can detect cracks of 0.05 in (1.27 mm) or greater in length and corrosion pits of 0.05 in x 0.05 in (1.27 mm x 1.27 mm) deep or greater, on the machined flat and forward face of the pintle housing. These dimensions are closer to the likely initiation size of a stress corrosion crack and should therefore improve the likelihood of crack detection using this technique. BAE Systems plan to update SB 32-A-JA851226 to incorporate the new HFEC technique by the end of June 2015. Heroux-Devtek will also update SB 32-19. EASA AD action will then be required to mandate the new procedure.

The current service bulletins relating to stress corrosion cracking in the forward pintle housing still employ the existing HFEC inspection technique. Until such times as the new HFEC technique is mandated, the AAIB has categorised the status of this Safety Recommendation as *'Partially Adequate - Open'*.

Further safety actions planned by the aircraft manufacturer

In addition to the steps previously described, BAE Systems plan to undertake the following safety actions to ensure the continued airworthiness of Jetstream 31 landing gear cylinders manufactured from DTD5094:

- Integration testing to determine if there are any mechanisms, other than the issue of adverse tolerances with the bearing locking pins, which might cause rotation or migration of the special washer. This relies on identification of a suitable operational aircraft on which to perform the integration testing.
- Identification of a higher-adhesion gasket material with better cure performance. The new gasket will be trialled in the integration tests.
- Updating SB 32-A-JA851226 to incorporate the new HFEC technique and instructions to inspect for corrosion pits as well as cracks.

- Revision of the maintenance documentation for the Jetstream 31 and 32 to reflect enhanced corrosion protection requirements for the forward face of the pintle housing.

Safety actions by the operator

Following the G-GAVA accident the operator decided to reduce the inspection intervals required by SB 32-A-JA851226. They amended their maintenance programme so that the HFEC inspection is performed every 700 landings or six calendar months, and the visual inspection is performed every 50 hours or 8 days, coincident with the service check. Additionally they have equipped each of their aircraft with an inspection mirror, so that flight crew can inspect the position of the special washer during the pre-flight walk-round.

Analysis

Failure of the landing gear

The ground marks on the runway from the failed landing gear and the left engine propeller, together with FDR data and audio analysis of the CVR, indicate that the left main gear failed eight seconds after touchdown. The aircraft weight was considerably below the maximum permissible landing weight and its descent rate and vertical acceleration were well within the design specification for the landing gear. As such the landing gear should not have failed.

Metallurgical analysis determined that the landing gear failed as a result of a crack which initiated from a corrosion pit on the forward face of the pintle housing. This crack propagated axially along the top of the pintle housing to a point where the remainder of the structure was unable to sustain landing loads and failed in sudden overload. The failure mechanism was identified as stress corrosion cracking, to which the DTD 5094 landing gear cylinders are known to be susceptible. It was not possible to determine how long the crack took to grow to failure, but the presence of corrosion and smeared gasket material on the fracture surfaces of the axial crack indicate that it was present for some time prior to final failure.

Rotational wear marks evident on the mating faces of the pintle housing and the washer were determined to have been caused by rotation of the washer, due to fouling by the bearing locking pins. This wear led to a degradation of the corrosion protection on the forward face of the pintle housing, exposing the surface of the aluminium to the environment. Observations of corrosion and salt contamination in the landing gear bays during the March 2014 maintenance input identified that the aircraft operated to coastal locations. Although the landing gear bays were cleaned at this time, continued salt contamination and poor cleaning of the landing gears, in combination with the exposed aluminium surface, is likely to have created an environment conducive to corrosion.

The manner in which the maintenance manager described performing the most recent routine visual inspections for stress corrosion cracking of the pintle housing, required by SB-32-A-JA851226 and SB 32-19, indicates that they were either not carried out, or not carried out effectively.

The last visual inspection of the pintle housing was documented as having taken place on 30 June 2014, 6½ weeks prior to the accident. It is not known whether the axial crack would have been visible at this time, and if so what length it might have been. The G-CCPW investigation determined that the visual inspections may be of limited effectiveness, especially if the crack size is small, and it was noted that a crack could grow rapidly in the interval between inspections. Nonetheless the inspection regime described in SB-32-A-JA851226 and SB 32-19 contributes to the continuing airworthiness of the JS31 landing gear legs manufactured from DTD 5094 and is mandated by EASA AD 2013-0208. It is possible that the manner in which the visual inspections were performed, and the presence of excess gasket material partially obscuring the inspection window in the washer tab, could have limited any opportunity to detect the crack had it been present.

Safety actions following the previous occurrence

Following publication of Safety Recommendation 2012-008, arising from the G-CCPW accident investigation, BAE Systems and EASA determined that the established inspection regime described in SB-32-A-JA851226 was inadequate. In their response to the recommendation EASA indicated that the HFEC inspection technique would be amended, and on this basis the AAIB categorised the status of the Safety Recommendation as 'Accepted – Closed.' However, despite the subsequent revision to the SB and the publication of EASA AD 2013-0208, no substantive changes were made to the HFEC technique, equipment or inspection intervals nor to the intermediate visual inspections. It is clear therefore that the actions taken did not meet the intent of Safety Recommendation 2012-008.

Due to the identified limitations of the HFEC inspection technique, the aircraft manufacturer decided to address the failure condition by placing increased emphasis on prevention rather than detection of stress corrosion cracking in the forward pintle housing. SB 32-JM7862 Revision 1 was introduced to install a protective washer on the forward face of the pintle housing, with the intent of preventing contact between the spigot bearing flange and the forward face of the pintle housing and removing the previously identified failure mechanism. However, this investigation determined that it is possible for the special washer to migrate/rotate out of position and in doing so, abrade the forward face of the pintle housing, degrading the surface protection and creating a condition where stress corrosion cracking can occur. It is therefore evident that SB 32-JM7862 Revision 1 did not meet its original design intent and failed to protect the forward face of the pintle housing from wear.

The most recent HFEC inspection on the forward pintle housing was performed in December 2013, at the same time SB 32-JM7862 was embodied on G-GAVA. The landing gear failed eight months later, four months before the next HFEC inspection was due.

The interim visual inspections did not detect the presence of a crack. It has not been possible to determine whether this was because the crack was not visible at the last inspection, or because the lack of cleaning and the manner in which the visual inspections were performed may have hindered its detection.

Identification of the fouling condition

The initial SB 32-JM7862 modification introduced a new split-bearing with a reduced-thickness flange to accommodate the new washer and gasket. However, it did not take account of the orientation of the spigot bearing cap, nor the extent to which the bearing locking pins might protrude beyond the bearing flange.

When BAE Systems first became aware of the potential for fouling between the bearing locking pins and the special washer, it was identified as an integration issue which might prevent reinstallation of the landing gear. BAE Systems received only one operator report of this issue and therefore assumed that the fouling condition could not exist on aircraft on which the landing gear had been successfully reinstalled. Nonetheless they issued SB 32-JM7862 Revision 2 to address the fouling condition, with instructions to transpose the spigot bearing cap at the next convenient maintenance input when the aircraft was jacked. For aircraft on which SB 32-JM7862 Revision 1 had already been embodied, the compliance time may have coincided with the next scheduled landing gear removal for HFEC inspection, and could therefore have been up to 12 months.

Prior to the G-GAVA accident, the manufacturer had not received any reports relating to migration of the special washer. In particular, neither the operator nor the third-party maintenance organisation had informed BAE Systems of the migrated washer findings on G-GAVA in March 2014 or the difficulties in installing SB 32-JM7862 Revision 1. BAE Systems was therefore unaware of the potential for rotation of the washer and did not recognise the relevance of the fouling condition in terms of its potential to degrade the surface protection on the forward pintle housing.

G-GAVA's left landing gear failed eight months after original embodiment of SB 32-JM7862, and within 5 months of the washer having been reinstalled. Revision 2 of SB 32-JM7862 had not been published at the time the washer was reinstalled in March 2014, and the next scheduled opportunity for embodiment of Revision 2 was not until December 2014.

Gasket material

In addition to the fouling condition identified with SB 32-JM7862 Revision 1, this investigation identified a number of issues with the gasket material. The third-party maintenance organisation who performed SB 32-JM7862 Revision 1 on G-GAVA expressed a number of concerns to the investigation about the curing instructions in the SB. Post-accident testing indicated that if the washer tab does not sit fully flush against the machined flat of the pintle housing, the gap might be too big to allow full anaerobic curing of the gasket, when subjected to the cure conditions described in the SB.

Following the accident, excess gasket material was found outside the profile of the washer tab on G-GAVA and no remaining gasket was evident of the forward face of the pintle housing. The third-party maintenance organisation were certain that all visible excess gasket material had been removed after the washer was reinstalled in March 2014. However, if the gasket under the washer tab had failed to cure fully, it could easily have

been squeezed out when the washer rotated. The rotating washer is likely to have destroyed the gasket on the forward face of the pintle housing.

As the gasket's primary function is to prevent moisture coming into contact with the forward face of the pintle housing, its absence, in combination with the mechanical damage, would have allowed corrosion to develop. The gasket material was originally chosen based on its low-adhesion properties, so that it could be easily removed for the regular HFEC inspections. However its low adhesive nature meant that the gasket would have been easily displaced by the mechanical force when the washer rotated. BAE Systems are in the process of defining a new gasket material with higher adhesive properties and better cure performance.

Safety actions to address the unsafe condition

SB 32-A-JA140940, published in October 2014, provided the means for a one-off inspection of all landing gears on which SB 32-JM7862 had previously been embodied at Revision 1 or 2. It also defined associated rectification actions to detect, repair and re-protect any damage which may have been induced to the forward face of the pintle housing in cases where rotation of the special washer was identified or suspected. The concurrently-issued SB 32-JM7862 Revision 3 provided enhanced instructions for reinstallation of the special washer and re-protection of the surface treatment on the pintle housing. Both SB 32-A-JA140940 and SB 32-JM7862 Revision 3, mandated by EASA AD 2014-0239, describe the required mitigations to address the unsafe fouling condition identified by this investigation. In addition the aircraft manufacturer has developed an enhanced HFEC inspection technique to reduce the detectable crack size, although this has yet to be published and mandated.

The aircraft manufacturer is also taking additional steps to assure the continued airworthiness of landing gear cylinders manufactured from DTD 5094 by investigating whether any other mechanisms have the potential to cause migration of the special washer or to induce similar damage to the pintle housing, identifying an improved gasket material and enhancing the associated maintenance documentation. These activities rely on the identification of an operational aircraft on which to perform integration testing. The aircraft manufacturer has been unable to confirm the timescale for completion of this trial and so the following Safety Recommendation is made:

Safety Recommendation 2015-013

It is recommended that the European Aviation Safety Agency require BAE Systems to expedite the proposed aircraft integration trial, to investigate whether any other mechanisms have the potential to cause migration of the special washer or to induce similar damage to the pintle housing.

In the event that the ongoing safety actions, when complete, do not adequately assure the continued airworthiness of the landing gear, the manufacturer has indicated that it may have to consider mandating the removal of DTD5094 landing gear cylinders from service.

Oversight of the operator and operator's maintenance organisation

The CAA terminated an audit of the operator and maintenance organisations' Part M and Part 145 approvals in January 2014 due to the number of issues identified in the Part 145 facility and a re-audit was not scheduled until seven months later. However, during the intervening period, the CAA continued to monitor both organisations and maintained a dialogue with the Accountable Manager and key personnel while they worked to re-establish compliance with their Part 145 approval. The CAA was satisfied that improvements were being made. Both operator and maintenance organisations were going through a period of organisational change with new staff appointed and other role changes. Due to the early termination of the January 2014 audit the Part M functions had not been examined. It was not until the July 2014 audit that some of the Part M issues became evident. In particular the CAA had not been made aware of the long-term sickness absence of the Continuing Airworthiness Manager and the adverse impact this had had on the technical records database and the forecasting of maintenance tasks.

A number of the Part M and Part 145 findings identified during the audit in July 2014, particularly those relating to technical records, Part M resources for continuing airworthiness tasks and available engineering resources, may have been pertinent to the manner in which the visual inspections were conducted on G-GAVA. However, the investigation did not determine whether these issues were contributory to the crack not being detected.

The CAA audit findings were verbally communicated to the Accountable Manager at the conclusion of the audit. They were not formally issued in writing until one month later but, throughout that period, there was ongoing communication relative to the findings, between the CAA and both organisations. G-GAVA's accident occurred in this intervening period, but it is unlikely that any actions arising from the CAA findings would have had any bearing on the outcome.

The operator and maintenance organisations did not adequately address the concerns identified in the audit findings to the satisfaction of the CAA. However, the CAA considered that the subsequent suspension of the maintenance organisation's Part 145 approval, and the contracting of all maintenance and selected Part M functions, provided an alternative acceptable solution. As a result of these actions, and the consequent dissolution of the operator's maintenance organisation, the investigation did not explore these issues further and therefore no additional Safety Recommendations have been made on these aspects.

Conclusion

The aircraft's left main landing gear failed as a result of stress corrosion cracking in the forward pintle housing, at the top of the left landing gear cylinder. The landing gear material is known to be susceptible to stress corrosion cracking. The investigation determined that a design solution implemented by the aircraft manufacturer following the 2012 accident, which was intended to prevent stress corrosion cracking, had not met its original design intent.

In light of the findings of this investigation, the aircraft manufacturer is taking additional steps to assure the continued airworthiness of landing gear cylinders manufactured from DTD 5094. In addition to the two Safety Recommendations made in AAIB Special Bulletin 5/2014 published on 2 September 2014, this final report contains one further Safety Recommendation to expedite that process.