AIR ACCIDENT INVESTIGATION & AVIATION SAFETY BOARD

ACCIDENT REPORT
A/C SX-SKY
AT HERAKLION AIRPORT
"N. KAZANTZAKIS"
12TH FEBRUARY 2009

Report no 08 / 2009

MINISTRY OF INFRASTRUCTURE, TRANSPORT AND NETWORKS

HELLENIC REPUBLIC
MINISTRY OF

AIR ACCIDENT INVESTIGATION & AVIATION SAFETY BOARD (AAIASB)

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ACCIDENT INVESTIGATION REPORT
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Accident of the a/c SX-SKY of Sky Express
at the Heraklion Airport "N. Kazantzakis" on 12th February 2010

The incident investigation was carried out by the Accident Investigation and Aviation Safety Board in accordance with:

- **ANNEX 13**
- **Hellenic Republic Law 2912/2001**
- **E.U. Directive 94/56**

The sole objective of the investigation is the prevention of similar accidents in the future.

The Accident Investigation and Aviation Safety Board

Chairman
Captain Akrivos D. Tsolakis

Members
George Kyriakopoulos
Lawyer

Triantaphilos Tsotinidis
Aeronautical Engineer

Secretary
John Papadopoulos

CONTENTS

OPERATOR	:	**SKY EXPRESS**[1]
OWNER	:	**SKY EXPRESS**
MANUFACTURER	:	**BRITISH AEROSPACE**
AIRCRAFT TYPE	:	**JETSTREAM 3100**
NATIONALITY	:	**GREEK**
REGISTRATION	:	**SX-SKY**
PLACE OF ACCIDENT	:	**HERAKLION AIRPORT "N. KAZANTZAKIS"**
DATE AND TIME	:	**12 FEBRUARY 2009, 17:23 h**
NOTE	:	**ALL TIMES ARE LOCAL TIME (LOCAL TIME = UTC+2h)**

SYNOPSIS

On 12 February 2009, during the landing of a Jetstream 3100 aircraft at the Heraklion Airport "N. Kazantzakis", and after the aircraft had covered a distance of 80 m approximately on the runway, the right main landing gear collapsed, folding backwards, and the right propeller came into contact with the runway. After a further distance of 930 m, which the aircraft covered with its left main landing gear operating normally but with collapsed right main landing gear being dragged along the runway, the aircraft came to a stop at 4.6 m to the right of the center line of the runway.

The Air Accident Investigation and Air Safety Board (AAIASB) was notified on the same date and by virtue of decision Ref. No AAIASB/269/12.02.09 of its Chairman an Investigation Team was appointed, consisting of Investigators Ioannis Papadopoulos as Investigator in Charge-, and Nikos Pouliezos, Member.

The draft final report was send to the UK Air Accident Investigation Branch for their comments as per Annex 13 of Chicago Convention. All the comments from the UK AAIB were taking into account in the report.

One safety recommendation was issued.

[1] *This report has been translated and published by the Hellenic Air Accident Investigation and Aviation Safety Board. As accurate as the translation may be, the original text in Greece should be considered as the work of reference.*

1 FACTUAL INFORMATION

1.1 History of Flight

Flight SHE 102/3 of 12 February 2009 was a scheduled passenger carrying flight performing the route Heraklion – Rhodes – Heraklion. The crew that was going to perform the flight reported for duty at 16:00 h.

The aircraft had earlier on the same day performed, with a different flight crew, four routes (Heraklion – Rhodes – Heraklion and Heraklion – Samos – Heraklion), without any problems being reported. Nothing had been observed during the pre-flight check.

The aircraft departed Heraklion at 16:55 h and landed at Rhodes at 17:35 h without incident.

At 18:30 h the aircraft departed Rhodes for Heraklion, carrying three crew members and 15 passengers. The pilot flying (PF) this particular sector was the Pilot in Command (PIC). At a distance of 30 nm from Heraklion and at a altitude of 7700 ft on its descent to 3000 ft, the crew informed the Air Traffic Control that it had the runway in sight and requested and was granted clearance to perform a visual approach.

The aircraft, fully configured for landing from a distance of 7nm, approached the airport for landing at runway 27. The wind information provided by the Air Traffic Control was 18 kt – 25 kt, from 210^{o}.

While approaching the runway, the PF asked the First Officer (FO) to check the angle of descent based on the APAPIs' of the runway. The FO confirmed the correct angle of descent, saying "one white, one red". The aircraft crossed the threshold with a speed of 112 kt and after flaring the PF reduced speed to Flight Idle and touched down with a speed of 86 kt.

As the speed was being gradually reduced, the PF had difficulty with controlling the aircraft along its longitudinal axis and noticing that the aircraft was leaning somewhat to the right, reported to the FO that "the gear has broken". Immediately afterwards, the blades of the right propeller of the aircraft struck the runway. As the aircraft continued to move with the left main landing gear wheel operating normally and the collapsed right main landing gear, folded backwards under the wing, being dragged along the runway, the crew stopped the engines, reported to the Airport Control Tower that the right landing gear had broken and requested evacuation.

The aircraft stopped in the runway with its nose wheel at 4.6 m to the right of the center line, at a distance of 930 m from the point of the propeller's first contact with the runway.

Immediately afterwards the PF ordered the cabin crew to open the cabin door and evacuated the aircraft, and the FO, who observed some fuel leaking from the right engine, switched off the electrical systems and requested through the Airport Control Tower that the fire trucks, which were on their way, to throw foam on the right wing to prevent any fire being started.

The passengers disembarked from the left aft door without any problems with the assistance of the cabin crew, while the fire trucks covered the right wing with foam as a preventive measure.

The airport, applying the standing procedures, removed the aircraft and released the runway for operation at 22:30 h.

During the period of time that runway 09/27 remained out of operation, two flights approaching the airport for landing were diverted to Chania Airport, and the departures of another three flights were delayed.

1.2 Injuries to Persons

Injuries	Crew	Passengers/Others
Fatal	---	---
Serious	---	---
Minor/None	--/03	--/15

1.3 Damage to Aircraft

1.3.1 Right Main Landing Gear (MLG)

The cylinder located at the upper end of the landing gear, which is fitted to spigots, was fractured at its front part, in the region of the fastener holes, as well as in Region A (Photos 1 & 2 and Figure 1/Appendix A).

The strut of the main landing gear was damaged. The MLG side mounting bracket was bent backwards, damaging its base fittings on the frame. The tire was burst and suffered severe deformation.

Photo 1

Photo 2

1.3.2 Right Wing

1.3.2.1 Wing Tip

The wing tip had sustained abrasion due to its contact with the runway surface. The abration/wear affects the whole wing tip assembly, and in particular the lower skin assembly, the flux generator which had been detached and separated from the frame, the outer section of the aileron, and the aileron trailing edge. Inboard on the aileron, the mass balance weight had sustained abrasion at its lower surface.

1.3.2.2 Flaps

The right wing's outboard trailing edge flaps had sustained abrasion damage to the trailing edge surface for approximately 18 in with the skin completely worn through. The outboard actuator fairing had also been heavily abraded at its rear corner edge. Additionally, the right wing flaps had been violently pushed upwards, which indicated that their driving system had suffered some kind of damage, considering that the respective left wing flaps were found in the position 'full down'. The inboard trailing edge flaps had sustained severe deformation at their outboard section, where the right main landing gear had pushed into and perforated the wing and, under the weight of the aircraft, 'twisted' it upwards, also causing the exhaust nozzle fairing to suffer deformation. The lower edge of the flaps had been damaged all over as a result of impact with the ground, and their structure had been bent backwards. The main flap had been significantly deformed along almost a third of its length starting from its outer tip, and this distortion caused its front edge to move upwards, which in turn had caused significant creasing of the frame at that point. In brief, the right wing flaps in that area had been violently pushed (because of the impact) upwards and their driving system had suffered damage. Additionally, the wing trailing edge in that area had been 'warped' upwards along approximately 30 in, with a width of 4 in. Finally, there were dents and distortions in the inner flap fairing and the individual components of its driving system were fractured.

1.3.2.3 Lower Wing Skin

Inside the right landing gear wheel well, where the landing gear was displaced, there was significant damage and warping noticeable in the lower wing surface/skin, particularly in the area impacted by the front gear support bracket, as it was bent backwards and sprang out of its main fittings. There was a crack in the skin in the distortion area, which followed a diagonal line towards the wheel well corner. Moreover, the metal casing in this area had warped and buckled downwards in the exterior end of the opening of the main gear well, where part of the casing formed the basis of the support beam holding the gear in place. Inside the same landing gear wheel well the mounting of the aft strut had been impacted by the broken landing gear. The support sheets/plates in the aft wing spar also bore marks and damage. The seal carriers around the rear section of the door had also been deflected upwards.

1.3.3 Main Landing Gear Door

The upper part of the right MLG door strut was significantly distorted and its hinge mechanism had suffered impact damage.

1.3.4 Baggage Pod

The baggage pod and the aft drainage system in the area had suffered extended damage because of their impact with the runway surface. Part of the baggage pod skin and core was missing, for a length approximately 24 in long and 10 in wide. Friction from the impact with the runway surface had disrupted the internal honeycomb until the lower surface of the structure. In front of that area, there was a puncture on baggage pod, approximately 6 in in length, accompanied by a ‘tearing’ penetrating the casing of the honeycomb and the interior casing of the assembly.

1.3.5 Right Engine-Propeller Assembly

The propeller had struck the ground with significant force and as a result all four of its blades had suffered extensive distortion. The spinner had been pushed upwards and backwards, and as a result the back plate had impacted the engine cowling. Also, the propeller blade counterweights had been detached from the hub.

The right engine crank, despite not displaying any apparent damage, could not be rotated when force was applied.

The leading edges of the upper and lower engine cowling were significantly damaged/worn as a result of the backwards pressure of the crank plate when the propeller struck the ground.

The remaining surface of the engine cowling above the baggage trolleys appeared to be in a normal condition, but their lower surface could not be checked because the aircraft was essentially resting on that surface.

1.4 Other Damage

Apart from scratches on the runway surface made by the propeller blades, no other damage was observed.

1.5 Personnel Information

1.5.1 Captain

The Captain was male, 63 years old.

Pilot License	:	Air Transport Pilot License in accordance with JAR-FCL ATPL(A) issued by the Hellenic Civil Aviation Authority
Type Ratings	:	Jetstream 31/32, valid until 23.05.2009 Jetstream 41, valid until 12.01.2010 TRI(A) on B747-100/300, Jetstream 31/32/41
Instrument Rating	:	IR(A)/MP, valid until 12.01.2010
CRM	:	Recurrent CRM Training, June 2008
Medical Certificate	:	JAR-FCL3, Class 1 valid until 14.08.09 and Class 2 valid until 14.02.10, with the restriction to wear corrective lenses.
Flying Experience	:	Total 24,000 h Type 570 h
Rest Period	:	24:30 h prior to his showing up for duty.

He had been hired by Sky Express in 2006, occupied the position of Flight Operations Manager and was TPE(A) in the Operator’s training organization.

He had previously worked for a commercial air carrier, performing flights as First Officer Captain and Captain on B747 100-300, A310/300-600, A340 type aircraft.

1.5.2 First Officer

The Captain was male, 37 years old.

Pilot License	:	Commercial Pilot License in accordance with JAR-FCL CPL(A) GR-001264 issued by the Hellenic Civil Aviation Authority
Type Ratings	:	Jetstream 31/32, valid until 22.02.2009 Jetstream 41, valid until 08.07.2009
Instrument Rating	:	IR(A)/MP, valid until 12.02.2010
CRM	:	Recurrent CRM Training, March 2008
Medical Certificate	:	JAR-FCL3, Class 1 valid until 13.03.09 and Class 2 valid until 13.03.11
Flying Experience	:	Total 1,800 h Type 250 h
Rest Period	:	72 h prior to his showing up for duty.

He had been hired by Sky Express in February 2008.

1.5.3 Cabin Attendant

Female 26 years old

She had 2000 h flight experience as cabin attendant.

She had been hired by Sky Express in February 2007.

1.6 Aircraft Information

1.6.1 General

The aircraft is a twin turboprop with a pressurized cabin.

Manufacturer	:	British Aerospace
Type	:	Jetstream 3102
Serial Number	:	829
Year of Manufacture	:	1988
Certificate of Registration	:	Registered in the Greek Register on 24.06.05
Certificate of Airworthiness	:	Valid until 19.06.09
Total Flight Hours	:	13,222.21 h
Total Cycles	:	15,349

Maximum Takeoff Mass : 15,562 kg
Maximum Landing Mass : 14,900 kg

The aircraft mass at the time of the incident was 14,870 kg. The center of gravity at landing was 26% MAC and within the limits.

The aircraft was fitted with two Garrett TPE331-10UGR514HD turboprop engines, power 127 PW, and two Dowty Propellers four-blade propellers.

Since June 2005, when it became part of the operator's fleet, it had performed 3,532.21 h of flight and 5,285 landings. On 30.01.09 it had passed a 800 h check and on 04.02.09 a 200 h check.

1.6.2 Undercarriage

The aircraft is fitted with a tricycle type forward retracting landing gear which is housed in the fuselage and is hydraulically controlled.

The landing gear and the relevant structure are designed to absorb power equivalent to a maximum descent rate of 10 fps when the aircraft is landing with the maximum design landing weight (i.e. maximum landing weight at maximum descent speed), in accordance with the requirements of EASA, CS 25 – Large Airplanes (para. 25.473 – 25.487). Moreover, in accordance with the CS-25,723 specifications, the main landing gears are designed to absorb power equivalent to a maximum descent rate of 12 fps, when the aircraft is landing with the maximum design landing weight.

1.6.3 Main Landing Gear

There is a cylinder at the upper end of the main bracket of each landing gear, which is fitted to spigots by means of threaded fasteners.

In order for the landing gear to be connected to the aircraft, the ends of the spigots rest inside housings in the main wing structure. The cylinder and the attached spigots rotate every time the undercarriage is lowered or retracted. The cylinder is loaded every time the aircraft lands.

The cylinder had been reduced in thickness in the region of area "A", Figure 1/Appendix A, in order that the anticipated fatigue cracking resulting from the cyclic loading would occur at this location.

Due to the fact that the regular checks after the removal of the landing gears from the aircraft had revealed cases of cracks in the above-mentioned area “A”, the manufacturer had issued Service Bulletin (SB) 32-A-JA851226 for Non Destructive Test (NDT) and visual inspection for traces of cracks in the area “A”. Next, the UK Civil Aviation Authority issued an Airworthiness Directive (AD G-003-01-86), adopting the above mentioned SB.

According to this:

(a) A Non Destructive Test is to be performed during the first overhaul of the landing gear or within three calendar months or 300 landings, whichever occurs earlier, from the issue of the compulsory SB, and to be repeated in one calendar year or every 1200 landings, whichever occurs first.

(b) Intermediate visual inspections will be conducted every 300 landings or three calendar months, whichever occurs earlier,

(c) A Non Destructive Test will also be carried out every 300 landings or three calendar months, whichever occurs first, after a heavy or abnormal landing.

According to the manufacturer, the main landing gears have a life of 50,000 cycles (landings) and the period between two overhaul is 6 years or 10,000 cycles, whichever occurs first.

The landing gear in question had completed 23,940 cycles since new and had been subjected to an overhaul by an EASA Part 145 maintenance organization on 17.09.08. The landing gear had been placed on the aircraft after the overhaul on 27.10.08 in accordance with the procedures described in chapter 32-10-11 of the manufacturer’s maintenance manual, by the operator’s maintenance organization, which is EASA Part 145-certified. From the date it was placed on the aircraft until the accident flight the landing gear had completed 148 cycles.

At the overhaul of 17.09.08 the SB had been carried out without findings.

The operator’s maintenance organization had performed on 02.01.09 a visual inspection, according to Part B of the SB, without findings (entry No 5136 in the Technical Log and issue of maintenance task card MWO SE/TD/MWO/SKY/S/6113).

1.7 Meteorological Information

The METAR issued at 17:20 h (15:20 h UTC) was the following:

“LGIR 121520Z 21013G23KT 9999 FE018TCU SCT025 15/16 Q1007”

At the time of the landing, the wind information provided by the Airport Control Tower was: “from 210^{o}, 18 kt, max 25 kt”.

1.8 Aids to Navigation

Not applicable.

1.9 Communications

Not applicable.

1.10 Airport Information

1.10.1 Heraklion Airport

The Heraklion Airport has two landing runways, 09/27 measuring 2,714 m X 45m and 12/30 measuring 1566 m X 50 m.

On 12.02.09, due to works being performed on runway 27, where the aircraft landed, its threshold had been displaced by 700 m and the landing distance available (LDA) was 2014 m.

The precision approach path indicator (PAPI) in runway 27, as a result of the threshold displacement, was inoperative and an abbreviated precision approach path indicator (APAPI – array of two housing assemblies) was placed at the displaced threshold set at 3^{o} (NOTAM 0225/09).

1.11 Flight Recorders

1.11.1 FDR

The aircraft was equipped with a Sunstrand type UFDR, Flight Data Recorder (FDR), (Part No: 980-4100-FWUS and Serial No: 4672), with a capacity of recording a limited number of parameters in a continuous looping tape for a period of 25 h, provided power was supplied.

The FDR readouts were performed at the premises of the UK Air Accidents Investigations Branch (AAIB). The following parameters were recorded: time, pressure altitude, indicated speed, vertical acceleration and aircraft heading.

The examination of the parameters shows that the aircraft was descending with a descent rate of 500 ft/min and a speed of 100 kt. At touch down the aircraft speed was 86 kt and the vertical acceleration 1.79 g (0.79 g over the gravity reference value which is 1g).

The right landing gear collapsed two seconds after the touchdown (Appendix B – Diagram (1), Graphic representation of the accident flight parameters).

Considering that the landing in question was a 'soft' landing, all the flight data contained in the FDR were decoded in order to examine whether they contained any 'heavy' landings.

Out of the 27 landings contained in the FDR data, in the 5th and 27th landings (counting the accident landing as 1st and working backwards a vertical acceleration of 2.5 g and 2.8 g, respectively, had been recorded (Appendix B – Diagrams (2) & (3), Graphic representation of the 5th and 27th landing parameters, respectively).

1.11.2 CVR

The aircraft was also equipped with a Fairchild Model A100A Cockpit Voice Recorder (CVR) (Part No: 93-A100-31 and Serial No: 15798), which recorded the conversations of the flight crew and the sounds picked up by the microphone in the cockpit in a continuous 30-min looping tape, provided power is provided. The quality of the recordings was very good.

1.12 Wreckage and Impact Information

On the Runway 27 at a distance of 730 m from the displaced, due to work in progress, threshold there are marks from the impact of the propeller blades, at 50 cm intervals. The propeller markings continue for 125 m, with the intervals between them increasing progressively to 70cm. The marks reappear after a distance of 340 m and continue for the next 80 m as the space between them increases to 1.7 m and the right landing gear begins to leave friction marks on the runway. Marks are reappearing again after 65 m and continue for the next 80 m and the space between successive propeller impacts increases to 2.6 m and then stop. In the next 240 m on the runway there are friction marks from the collapsed landing gear and the fuselage.

The total distance the aircraft covered from the point of initial contact with runway to the point, where it stopped, was about 1010 m.

1.13 Medical Information

Not applicable.

1.14 Fire

Not applicable.

1.15 Survival Aspects

Even though there was no requirement for the aircraft crew to include a cabin crew member, considering that the maximum approved seat configuration did not exceed 19 seats (OPS-1.990), the air carrier, thinking of passenger safety, had established the use of one cabin crew member in each aircraft flight.

After the aircraft stopped, the cabin attendant immediately opened the aft left door and the passengers left the aircraft in an orderly manner, without any panic, being unable to see the right side where the landing gear had collapsed and thus simply assuming that the right wheel tire had burst.

The presence of the cabin attendant was positive, because without her assistance one of the flight crew members would have been required to leave the cockpit, cross the aircraft and open the passenger exit door, which would have produced a delay.

1.16 Tests and Research

In order to establish how did the fracture of the right main landing gear cylinder occurred and to assess the time of fracture, the fractured parts of the cylinder were transported to the premises of the UK AAIB and then to the Material Integrity Group (MIG) of the Navy Command of the Royal Navy of the United Kingdom, which has expertise in cases of aviation material failure.

The conclusion of these tests was (see Appendix C) that:

"The undercarriage cylinder ex BAE Jetstream 31 SX-SKY failed as the result of ductile overload. This is likely to have been the result of a heavy aircraft landing."

1.17 Organizational and Management Information

1.17.1 Air Carrier

The air carrier Sky Express S.A. is a public transport company and has a valid AOC, issued under Ref. No GR-021 by the Hellenic Civil Aviation Authority for the transport of passengers and cargo.

Its fleet included 2 Jetstream 31/32 and 2 Jetstream 41 aircraft.

The air carrier has an EASA, Part 145 maintenance organization approved for line maintenance under Ref. No EL.145.041, with an EASA Part M Continuing Airworthiness Management Organization (CAMO) approval issued under Ref. No EL.MG.002.

The base maintenance of the air carrier's aircraft was carried out by the maintenance organization, Air Support International, in Italy. The failed landing gear overhaul was carried out at the premises of APPH Aviation Services Ltd, an EASA Part 145 organization approved by the UK Civil Aviation Authority under Ref. No UK.145.00354.

1.18 Additional Information

After the accident, the left landing gear was also removed from the aircraft and the spigot housing was checked using 'Eddy Current' ultrasounds for cracks, without findings.

The landing gears of the air liner's other Jetstream 32 were also removed and checked, and the aircraft was grounded after the accident and until the check.

1.19 Useful or Effective Investigation Techniques

Not applicable.

2 ANALYSIS

The accident landing during which the aircraft's right main landing gear cylinder was fractured was a 'soft' landing and the recorded vertical acceleration value, 1.79 g, could not have produced alone the fracture. According to the results of the tests (Appendix C):

The cylinder material was considered to be metallurgically sound and was consistent with aluminium zinc alloy DTD 5094.

The chevron markings on fracture surfaces "A2" and "B2" 'pointed back' to the inboard edge of the cylinder (Appendix C / Figures 4 & 5), indicating that initiation had taken place at this location. These fracture surfaces were more heavily corroded than “A1” and “B1” (Appendix C, Figures 3 & 6), and were likely to have been formed prior to the two cracks that had formed “A1” and “B1”. Therefore, fracture surfaces “A2” and “B2” formed the first crack in the failure sequence. This first crack initiated and propagated in Region “A” (Appendix C, Figure 1), as would be anticipated since this was the region where the NDT was carried out. The first crack propagated from the inboard edge of the cylinder, increasing the loading upon the cylinder material surrounding the threaded fasteners, sites of stress concentration. The second and third cracks then initiated at these sites of stress concentration and propagated within the cylinder to form fracture surfaces “A1” and “B1”. In support of this the chevron markings on fracture surfaces “A1” and “B1” pointed back to the regions of the threaded fasteners.

The region on fracture surfaces “A2” and “B2” of black appearance is consistent with post failure staining. The evidence in support of this being the uninterrupted nature of the features such as chevrons upon these fracture surfaces.

The ductile overload failure of the undercarriage cylinder is likely to have resulted from a ‘heavy’ landing made by the aircraft. The corroded nature of the fracture surface belonging to the first crack that had formed indicated that this failure may have occurred during the heavy landing. This would have weakened the cylinder and made it susceptible to failure during a subsequent landing. The ‘heavy’ landing would have imposed a heavy upwards force on the spigot and the associated fasteners and in turn a bending stress upon the cylinder material within Region “A”, initiating the first crack.

The FDR recordings establish that a ‘heavy’ landing had taken place on 07.02.09, as a vertical acceleration of 2.8 g had been recorded, as well as on the first flight of 12.02.09 (date of the accident), where a vertical acceleration of 2.5 g had been recorded. From the two above landings it is probable that the landing of 07.02.09 was the one that caused the initial crack in Region “A” (fracture surfaces “A2” and B2”) and the first landing of 12.02.09 the one that propagated the crack and created the second and third cracks in the region surrounding the threaded fasteners, which after four landings spread and caused the landing gear cylinder to fracture.

The visual inspection of Region “A” of the main landing gears pursuant to part B of the SB had been carried out on 02.01.09 (36 days prior to the first ‘heavy’ landing), and therefore the initiation of the crack was not noticed.

If the ‘heavy’ landing of 07.02.09 had been reported, the check prescribed in the aircraft’s Maintenance Manual after a ‘heavy’ landing would have been carried out. The second

‘heavy’ landing report, on 12.02.09, which again was not made, would have forced the company’s maintenance crew to carry out again the above check and if that check was performed on that day (12.02.09) then the maintenance crew would have located the crack or cracks and the fracture which occurred after four flights would have been avoided.
Considering that the aircraft does not have an instrument or device indicating when a landing is ‘heavy’, the characterization of the nature of each landing is a purely subjective matter depending on the impression of the flight crew. The flight crews, considering the above and the possible consequences of an unreported ‘heavy’ landing, should be particularly careful and sensitive in this matter.

3 CONCLUSIONS

3.1 Findings

3.1.1 The flight crew met all the requirements for the performance of the flight.

3.1.2 The aircraft was airworthy.

3.1.3 The aircraft’s landing gears have a life of 50,000 cycles (landings) and the interval between two overhauls is six years or 10,000 cycles, whichever comes sooner.

3.1.4 The fractured landing gear had completed 23,940 cycles since new and had been subjected to an overhaul on 17.09.08. Since then and as of the date of the accident it had completed 148 cycles.

3.1.5 The aircraft manufacturer had issued an SB, and the UK Civil Aviation Authority an AD, asking for tests and inspection applicable to Region “A” of the main landing gear cylinders.

3.1.6 Said AD had been carried out without findings in the course of the landing gear overhaul of 17.09.08 by an EASA-Part 145 approved maintenance organization.

3.1.7 On 02.01.09 a visual inspection of Region “A” of the main landing gear cylinders was carried out by the aircraft operator’s maintenance organization, in accordance with Part B of the SB, again without findings.

3.1.8 On 07.02.09 and in the morning of 12.02.09 the aircraft made ‘heavy’ landings considering that vertical acceleration values of 2.8 g and 2.5 g, respectively, had been recorded. None of these landings had been recorded in the aircraft’s log in order to trigger the inspection prescribed in the aircraft’s maintenance manual after a ‘heavy’ landing.

3.1.9 According to the technical examination of the fractured parts, the first crack developed in Region "A" (fracture surface "A2-B2") increasing the loading upon the cylinder material surrounding the threaded fasteners, sites of stress concentration. The second and third cracks then initiated at the site of stress concentration and propagated within the cylinder to form fracture surfaces "A1" - "B1" in the region surrounding the threaded fasteners. The cracks and the fracture resulted from the ductile overload of the undercarriage cylinder which is likely to have resulted from a 'heavy' landing made by the aircraft.

3.2 Probable Causes

Landing gear cylinder failure because of ductile overload resulting from a 'heavy' landing made by the aircraft.

4 SAFETY RECOMMENDATIONS

4.1 **2010 - 08** A recommendation should be made to the operator's pilots to record in the aircraft's log instances when there is even a suspicion of 'heavy' or abnormal landings, in order for the prescribed checks to be carried out.

Athens, 06 October 2010

THE CHAIRMAN

Akrivos Tsolakis

THE MEMBERS

G. Kyriakopoulos

Tr. Tsitinidis

Exact Copy
The Secretary

J. Papadopoulos

APPENDIX A

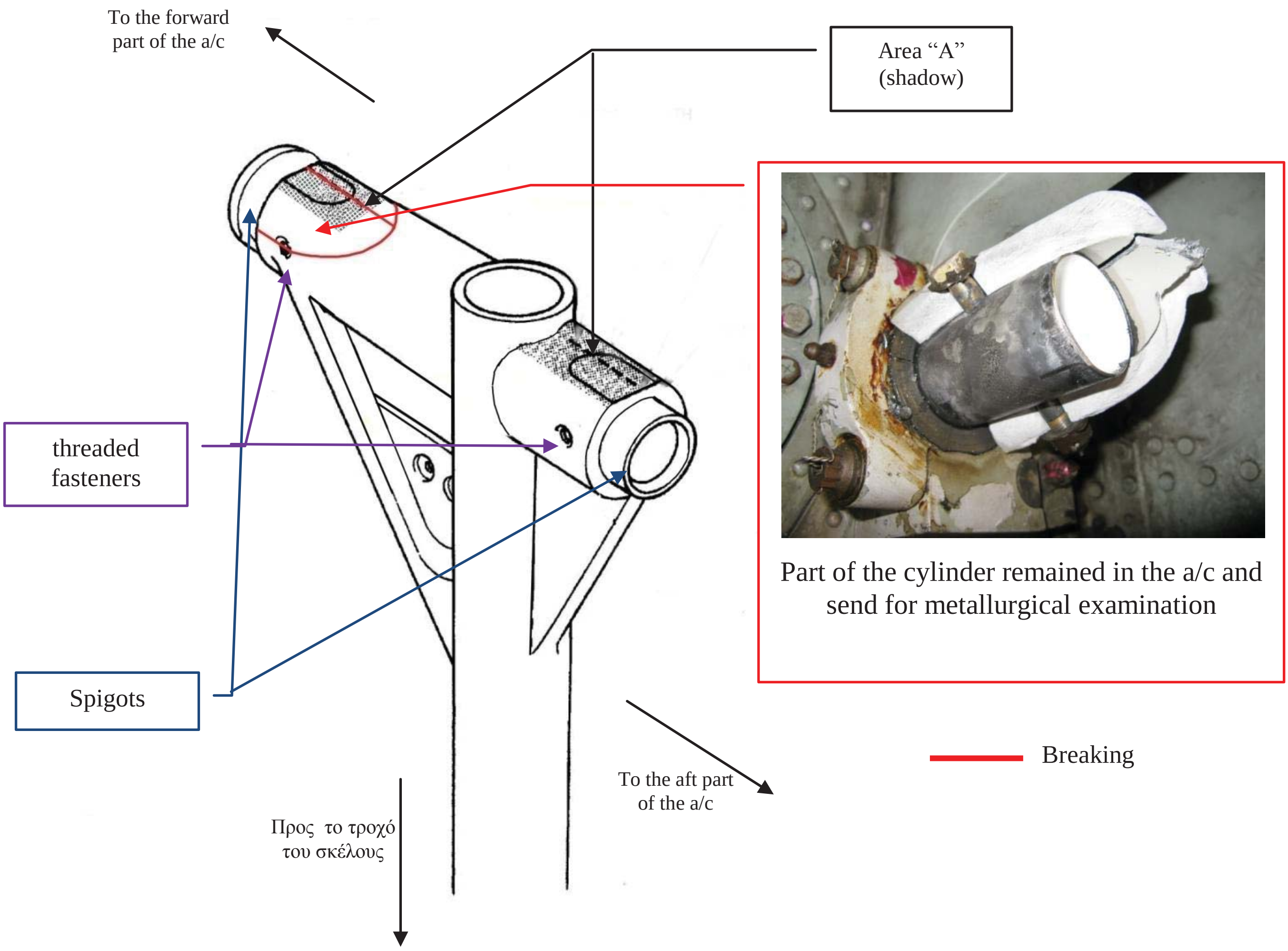

Figure 1

APPENDIX B

Diagrams with the plots of the FDR’s parameters

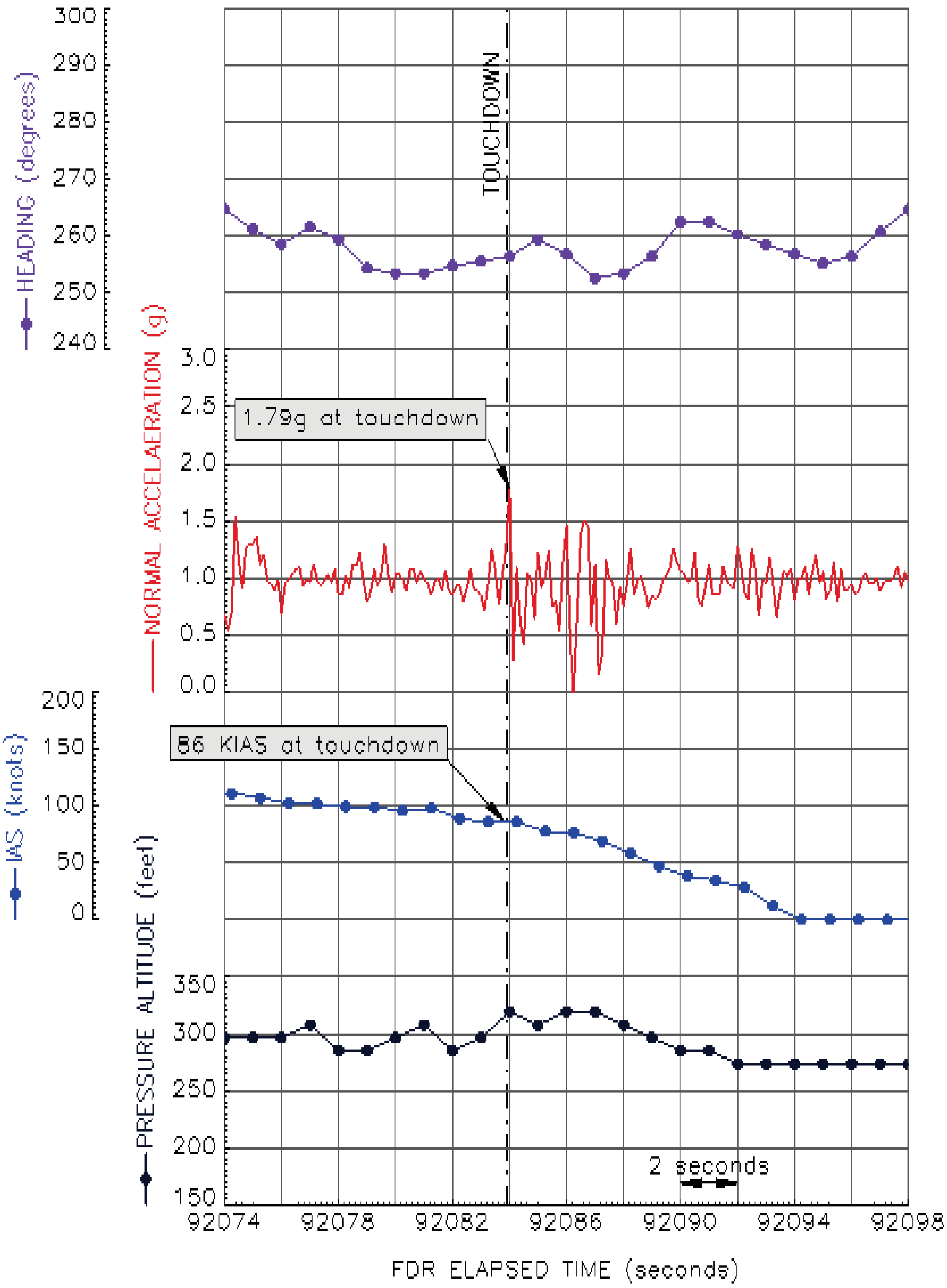
HEADING (degrees)
300
290
280
270
260
250
240
TOUCHDOWN
NORMAL ACCELAERATION (g)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1.79g at touchdown
IAS (knots)
200
150
100
50
0
86 KIAS at touchdown
PRESSURE ALTITUDE (feet)
350
300
250
200
150
2 seconds
92074
92078
92082
92086
92090
92094
92098
FDR ELAPSED TIME (seconds)

Diagram 1

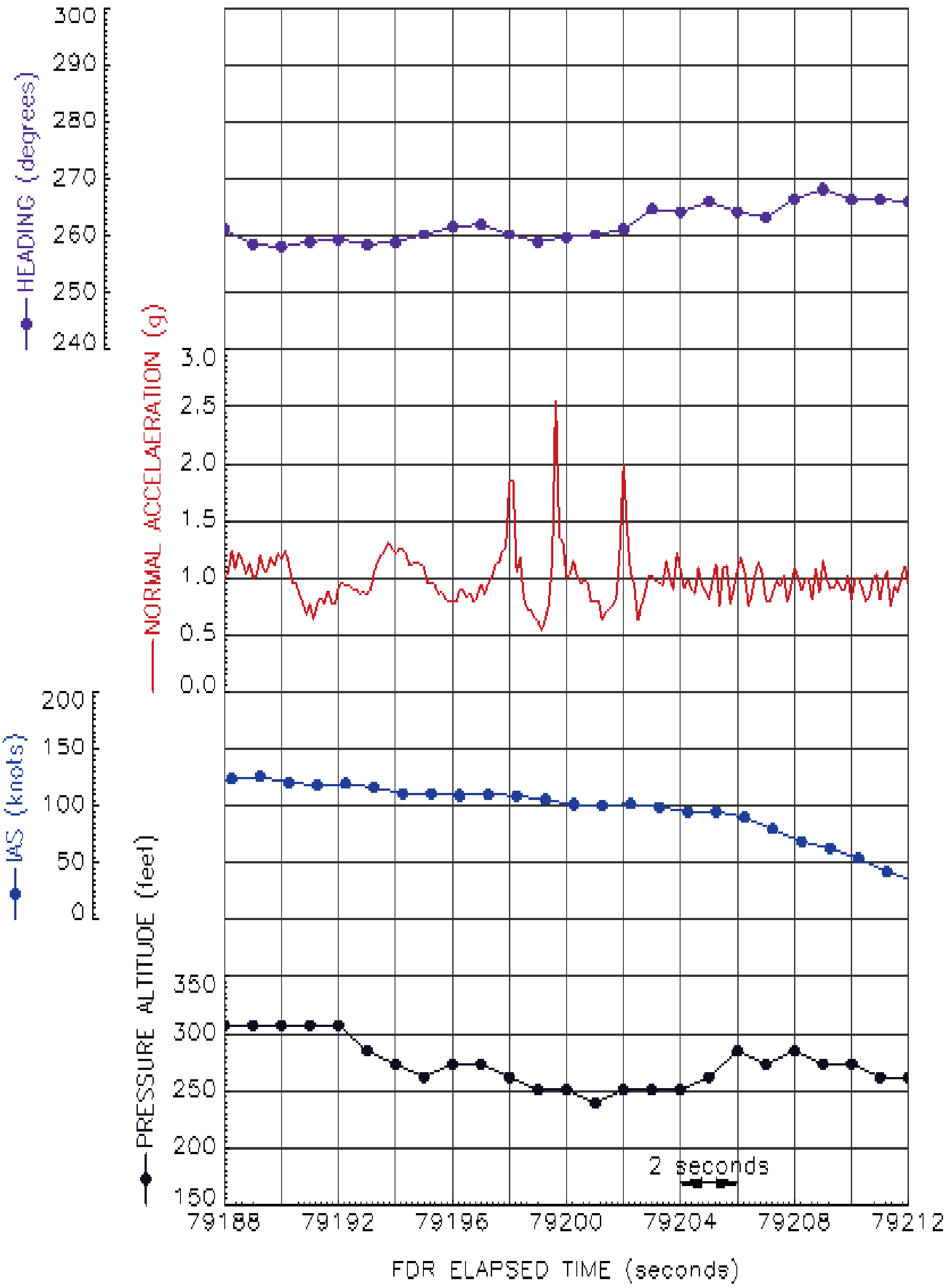
HEADING (degrees)
300
290
280
270
260
250
240
NORMAL ACCELAERATION (g)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
IAS (knots)
200
150
100
50
0
PRESSURE ALTITUDE (feet)
350
300
250
200
150
2 seconds
79188
79192
79196
79200
79204
79208
79212
FDR ELAPSED TIME (seconds)

Diagram 2

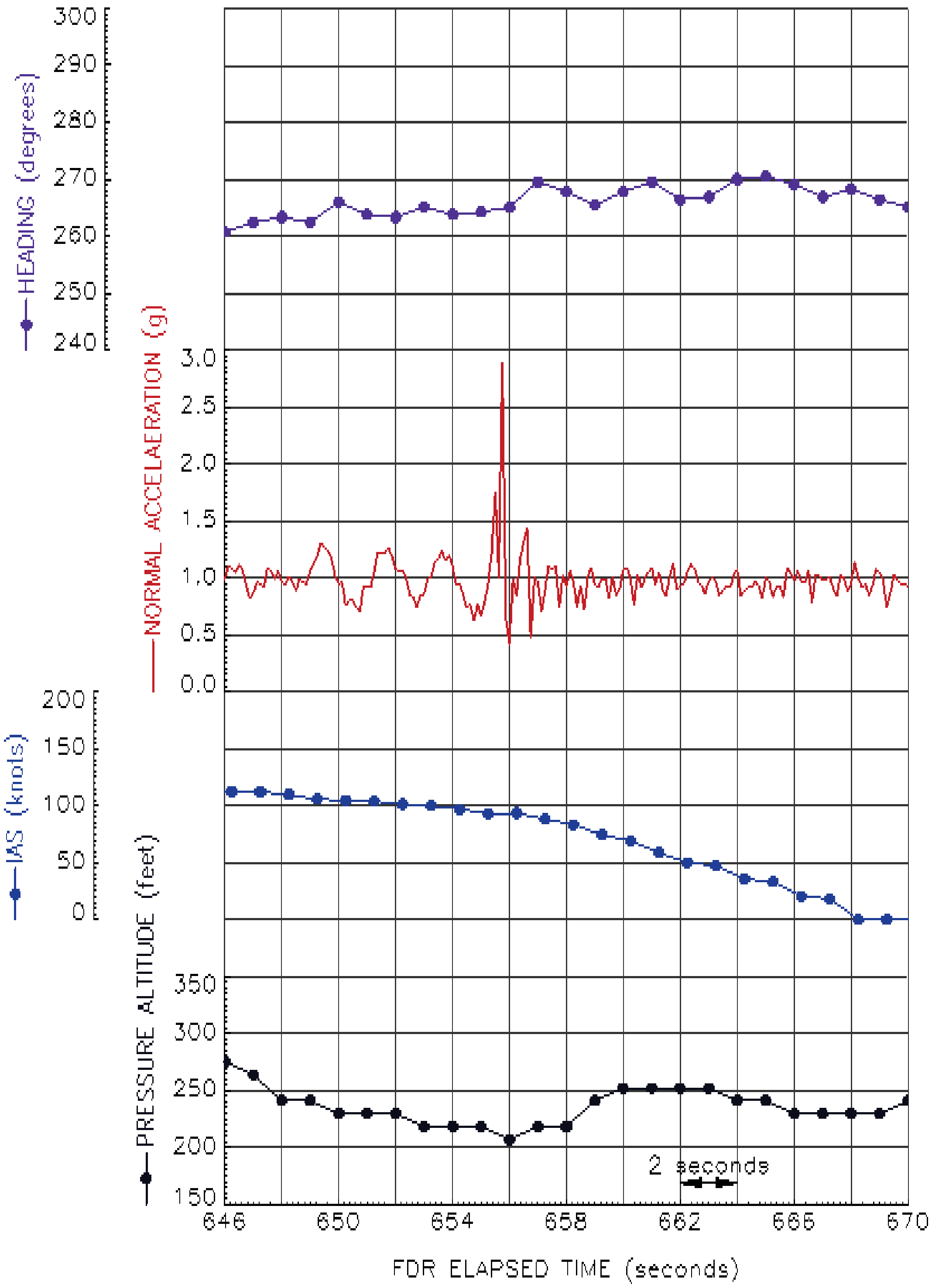
HEADING (degrees)
300
290
280
270
260
250
240
NORMAL ACCELAERATION (g)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
IAS (knots)
200
150
100
50
0
PRESSURE ALTITUDE (feet)
350
300
250
200
150
2 seconds
646
650
654
658
662
666
670
FDR ELAPSED TIME (seconds)

Diagram 3

APPENDIX C

Metallurgical Examination Report by

UK Royal Navy, Navy Command

Fleet FS (Air) Materials Integrity Group (MIG)

MATERIALS INTEGRITY GROUP

TECHNICAL MEMORANDUM MIG 08.371

File Reference: FFSA/9000/800/03/100057 /18007.1 MIG

INVESTIGATION OF FAILED UNDERCARRIAGE EX BAE JETSTREAM 31 SX-SKY

1. REFERENCES

A. Tasking: Meeting Raistrick, Pitt, Symonds (MIG), Jarvis (AAIB), Pouliezos (Greek Ministry of Transport and Communications Air Accident Investigation and Aviation Safety Board) dated 4 March 2009.

B. E mail from Jarvis (AAIB) to Symonds (MIG) dated 20 February 2009.

C. AP Precision Hydraulics Ltd Overhaul Manual Chapter 32-10-1 July 2008 Pages 501 to 506.

2. INTRODUCTION

2.1. Fleet Forward Support (Air) Materials Integrity Group (MIG) was requested (Reference A) to investigate the failure mode of the undercarriage cylinder ex BAE Jetstream 31 SX-SKY. It is understood (Reference A and Reference B) that the left main landing gear collapsed during landing at Heraklion, Greece. MIG was informed (Reference A) that the landing gear had completed 23940 cycles and had been subjected to regular Non Destructive Test (NDT) checks (References C) in the region of the failure revealing an absence of faults.

3. DETAILS OF UNDERCARRIAGE CYLINDER

3.1. The undercarriage cylinder was fitted to two steel spigots by means of a pair of threaded fasteners, Figure 1. The cylinder and the attached spigots rotated in a clockwise direction looking inboard everytime the undercarriage was lowered. Subsequently the cylinder was loaded by the fasteners every time the aircraft landed, Figure 2. The cylinder would have experienced a bending stress in the region of 'Area 'A'', Figure 1, and compressive stresses at the fastener holes. The cylinder had been reduced in thickness in the region of 'Area 'A', Figure 1 in order that the anticipated fatigue cracking resulting from the cyclic loading would occur at this location. The cylinder was regularly NDT tested in 'Area 'A'', Figure 1, in order to detect the fatigue cracking (Reference C).

4. EXAMINATION

4.1 Visual examination

4.1.1 The two remnants of the undercarriage cylinder were received by MIG (Reference A) designated Remnants 'A' and 'B', Figure 2. Remnant 'A' was still attached to the spigot, Figure 3 and Figure 4, whilst Remnant 'B' was loose, Figure 5 and Figure 6. There were two main fracture surfaces present upon Remnant 'A' designated 'A1' and 'A2', Figure 3 and Figure 4 respectively, and similarly on Remnant 'B' designated 'B2' and 'B1', Figure 5 and Figure 6 respectively. All the fracture surfaces were subjected to a visual examination using a binocular microscope.

4.1.2 Fracture surface 'A1' was rough and matt light grey in appearance with chevron and river markings present "pointing back" to the fastener hole where the threaded fastener had been fitted, Figure 3, Figure 7 and Figure 8. The light grey appearance was consistent with extensive post failure corrosion being absent.

4.1.3 Fracture surface 'A2' was also rough and matt dark grey in appearance with the exception of an area that was black in appearance where the fracture surface had been adjacent to the spigot, Figure 4, Figure 9 and Figure 10. The remainder of the surface was dark grey in appearance consistent with post failure corrosion having taken place. The chevron markings were again present "pointing back" to the inboard edge of the cylinder, Figure 1 and Figure 9.

4.1.4 Fracture surface 'B2' had mated with 'A2' and had similar features to those revealed on 'A2' as would be anticipated, Figure 11.

4.1.5 Fracture surface 'B1' was similar in appearance to 'A1', rough and matt light grey in appearance with chevron and river markings present "pointing back" to the fastener hole where the threaded fastener had been fitted, Figure 12 and Figure 13.

4.1.6 The chevron markings present upon fracture surfaces 'A2' and 'B2' that had mated together were examined in greater detail revealing the markings traversed the region that was black in appearance, Figure 14.

4.2 Examination using scanning electron microscopy

4.2.1 Fracture surface 'B2' was examined using Scanning Electron microscopy (SEM) in order to reveal any features of interest at the inboard edge of the surface and the region of black colouration. Features were revealed consistent with the fracture surface being corroded and smeared at the inboard edge, Figure 15.

4.2.2 However within the region of black colouration and dark grey regions, features consistent with ductile microvoid coalescence and corrosion were revealed, Figure 16 and Figure 17. It is considered that the corrosion had occurred post failure. There was an absence of features associated with either fatigue or stress corrosion.

4.3 Optical microscopy

4.3.1 A microsection was prepared through the inboard edge of fracture surface ‘B1’ the location to which chevron markings “pointed back”. Optical microscopy revealed an absence of features associated inclusions and pits adjacent to the fracture surface. A minor amount of localised intergranular corrosion was present consistent with post failure electrolyte ingress.

4.3.2 The microstructure was as anticipated of a hot worked aluminium alloy, consisting of aligned equiaxed grains and a small amount of intermetallic compound.

4.4 Metallurgical verification

4.4.1 The microsection was employed to carry out metallurgical verification. The elemental composition was determined using SEM and semi quantitative Energy Dispersive X-ray (EDX) analysis. The elemental composition of the cylinder material was consistent with DTD 5094, the aluminium zinc alloy specified on the component drawing.

4.4.2 It was not practically possible to measure the mechanical properties by tensile testing. The hardness of the cylinder material was a mean of 166 HV30 this is considered to approximate a tensile strength of MPa in excess of the 480 MPa specified for alloy DTD 5094.

5. DISCUSSION

5.1. The undercarriage cylinder ex BAE Jetstream 31 SX-SKY had failed as the result of ductile overload. In support of this the fracture surfaces were rough in appearance with chevron, river markings and features consistent with ductile microvoid coalescence present. There was an absence of evidence of any other failure mechanism.

5.2. The chevron markings on fracture surfaces ‘A2’ and ‘B2’ “pointed back” to the inboard edge of the cylinder indicating that initiation had taken place at this location. These fracture surfaces were more heavily corroded than ‘A1’ and ‘B1’ were likely to have been formed prior to the two cracks that had formed ‘A1’ and ‘B1’. Therefore fracture surfaces ‘A2’ and ‘B2’ formed the first crack in the failure sequence. This first crack initiated and propagated in Region ‘A’, Figure 1, as would be anticipated since this was the region where the NDT was carried out. The first crack propagated from the inboard edge of the cylinder, increasing the loading upon the cylinder material surrounding the threaded fasteners, sites of stress concentration. The second and third cracks then initiated at these sites of stress concentration and propagated within the cylinder to form fracture surfaces ‘A1’ and ‘B1’. In support of this the chevron markings on fracture surfaces ‘A1’ and ‘B1’ pointed back to the regions of the threaded fasteners.

5.3. The region on fracture surfaces ‘A2’ and ‘B2’ of black appearance was consistent with post failure staining. The evidence in support of this being the uninterrupted nature of the features such as chevrons upon these fracture surfaces.

5.4. The ductile overload failure of the undercarriage cylinder is likely to have resulted from a heavy landing made by the aircraft. The corroded nature of the fracture surface belonging to the first crack that had formed indicated that this failure may have occurred during the heavy landing. This would have weakened the cylinder and made it susceptible to failure during a subsequent landing. The heavy landing would have imposed a heavy upwards force on the spigot and the associated fasteners and in turn a bending stress upon the cylinder material within Region ‘A’, initiating the first crack.

5.5. The cylinder material was considered to be metallurgically sound and was consistent with aluminium zinc alloy DTD 5094.

6. CONCLUSIONS

6.1. It has been determined that he undercarriage cylinder ex BAE Jetstream 31 SX-SKY failed as the result of ductile overload. This is likely to have been the result of a heavy aircraft landing.

7. DISTRIBUTION

AAIB 1 copy (Mr M Jarvis, Senior Inspector of Accidents)
MIG 2 copies + Original

8. FIGURES

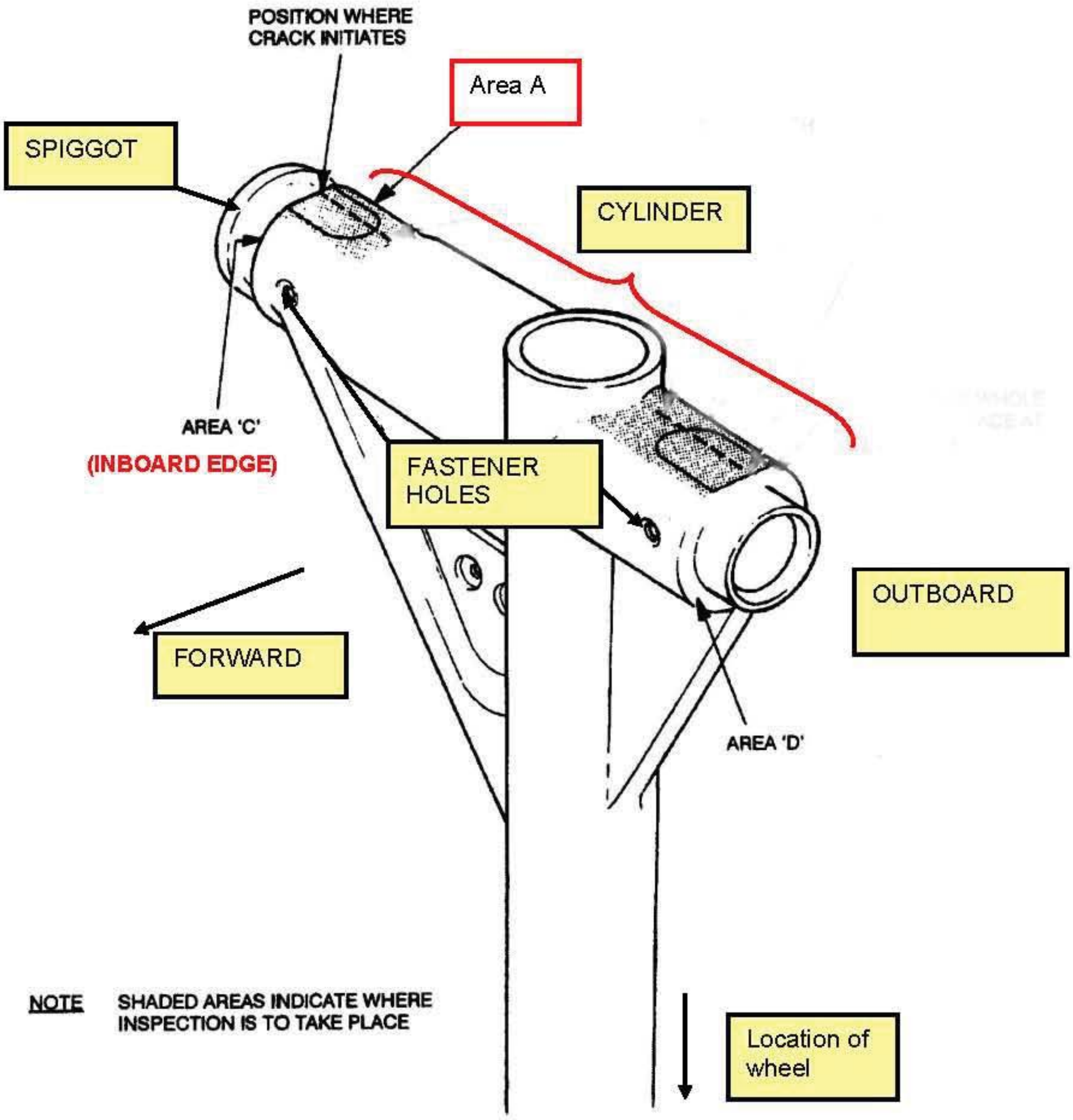

Figure 1: Showing the undercarriage cylinder (Reference C). NTS

5

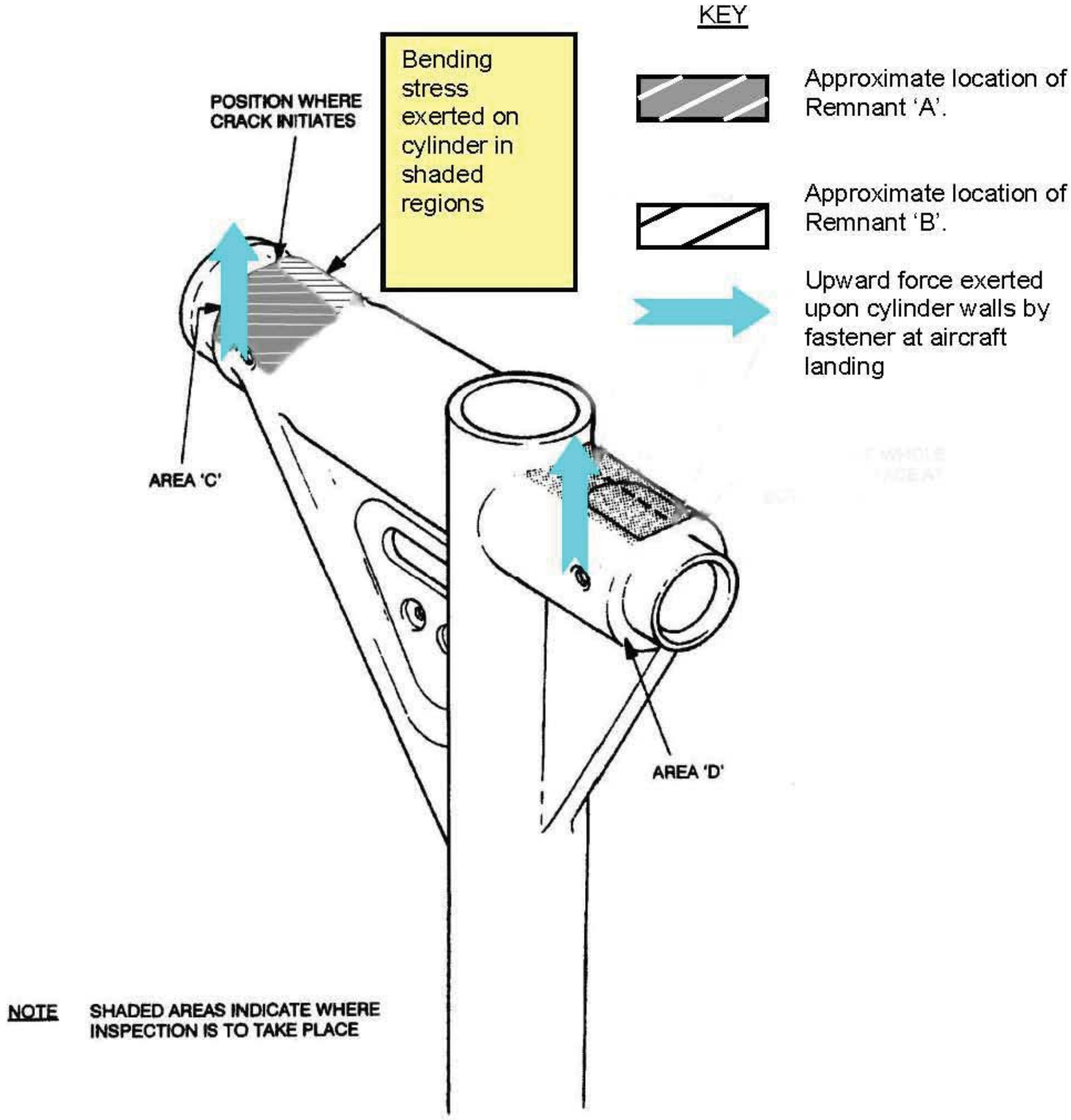

Figure 2: Showing the: undercarriage cylinder; location of Remnants 'A' and 'B'; the loading imposed on aircraft landing.

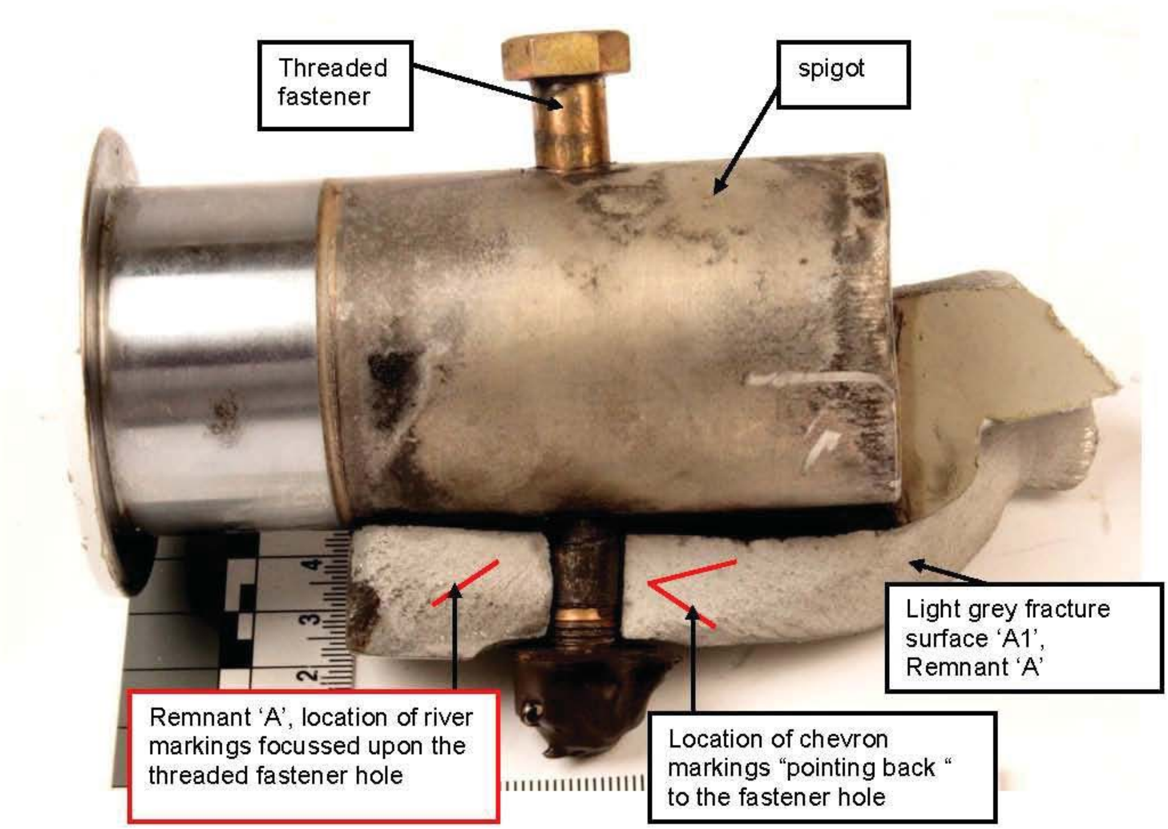

Figure 3: Showing the as received spigot and remnant ‘A’ of the undercarriage cylinder.

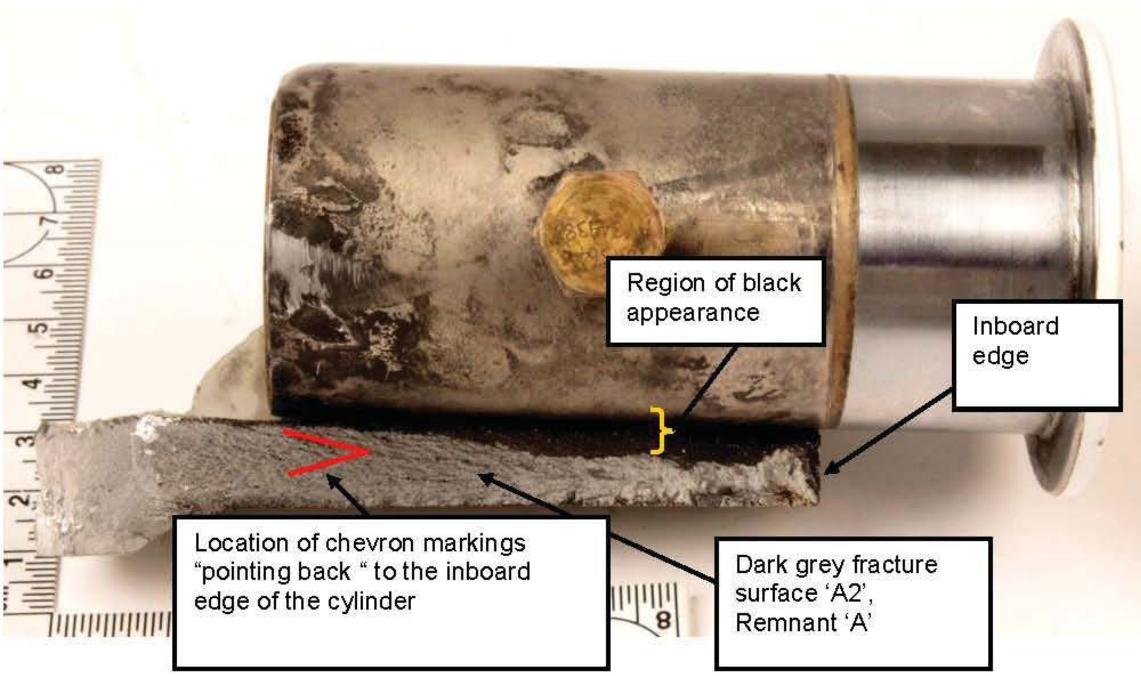

Figure 4: Showing the as received spigot and remnant ‘A’ of the undercarriage cylinder.

7

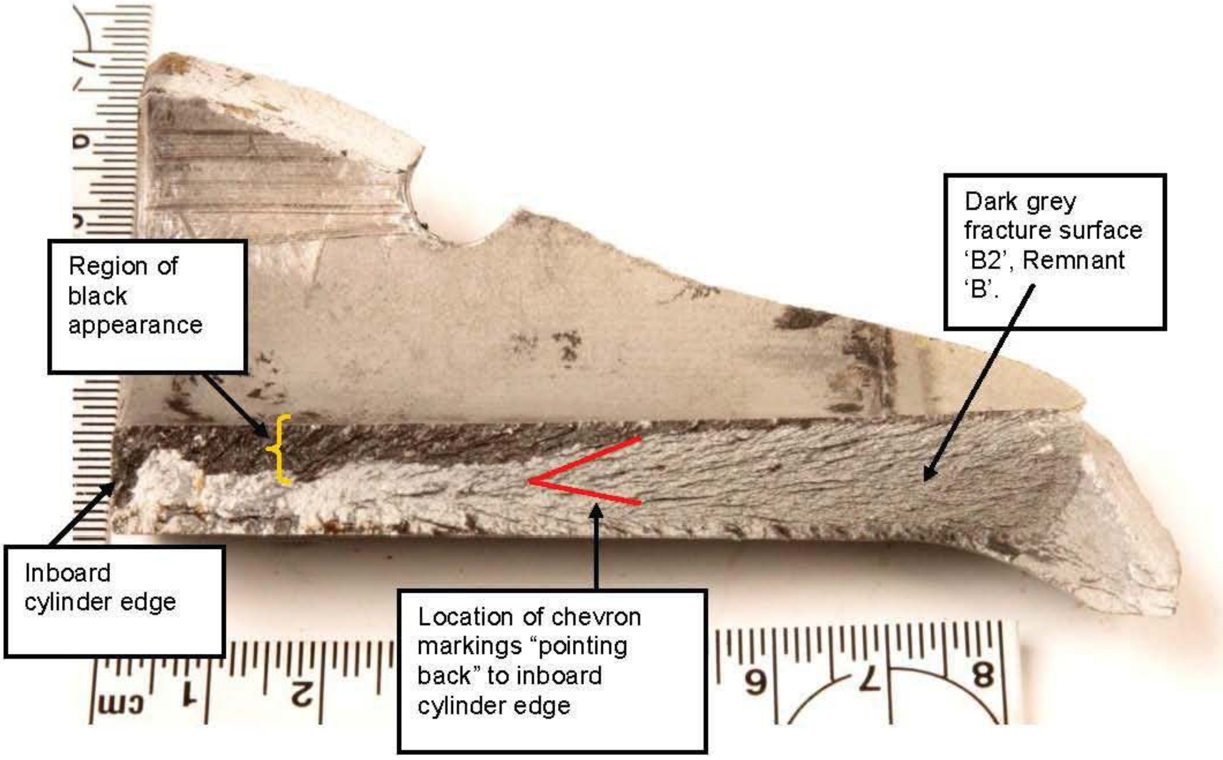

Figure 5: Showing the as received remnant 'B' of the undercarriage cylinder and fracture surface 'B2'.

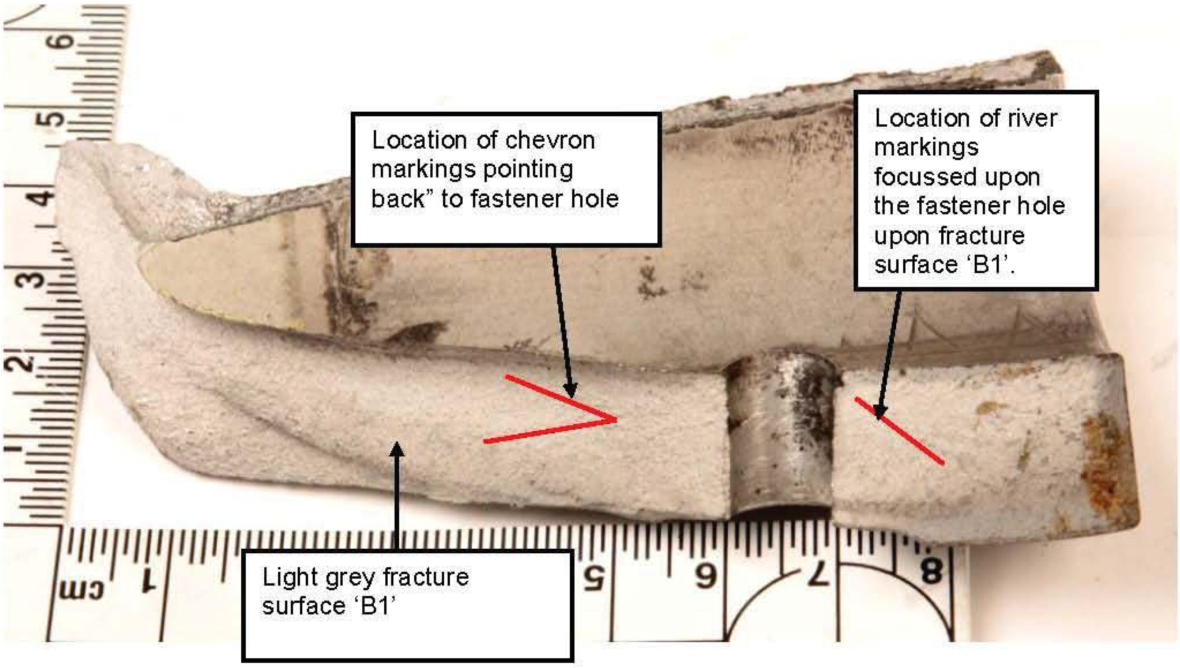

Figure 6: Showing the as received remnant 'B' of the undercarriage cylinder and fracture surface 'B1'.

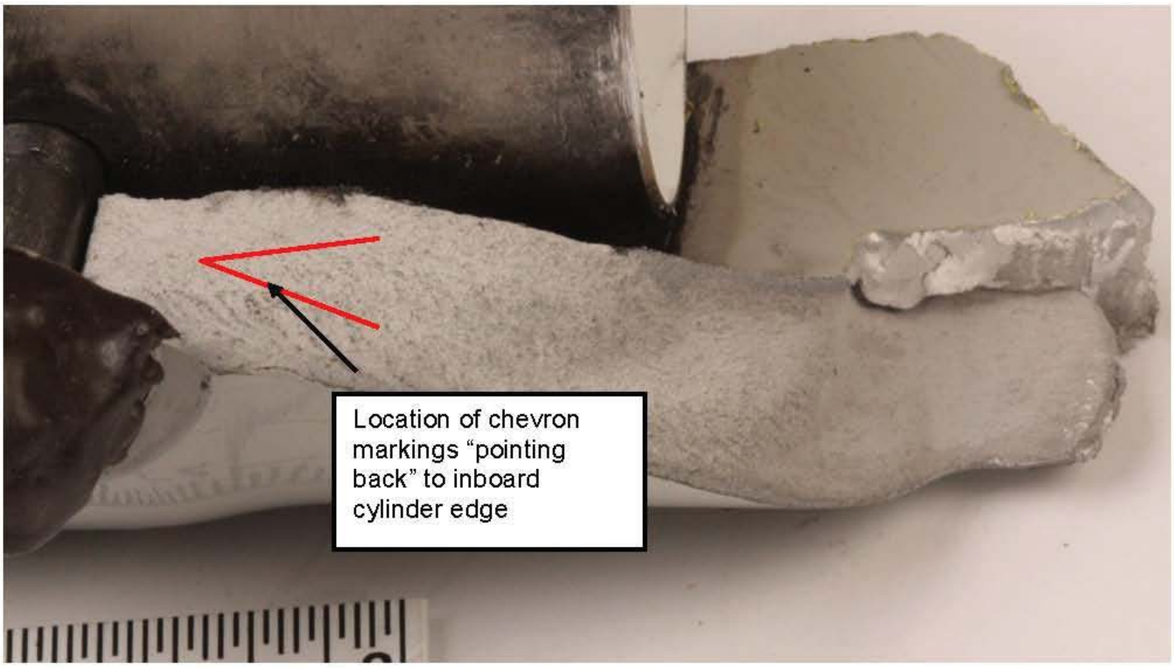

Figure 7: Showing fracture surface 'A1' in detail.

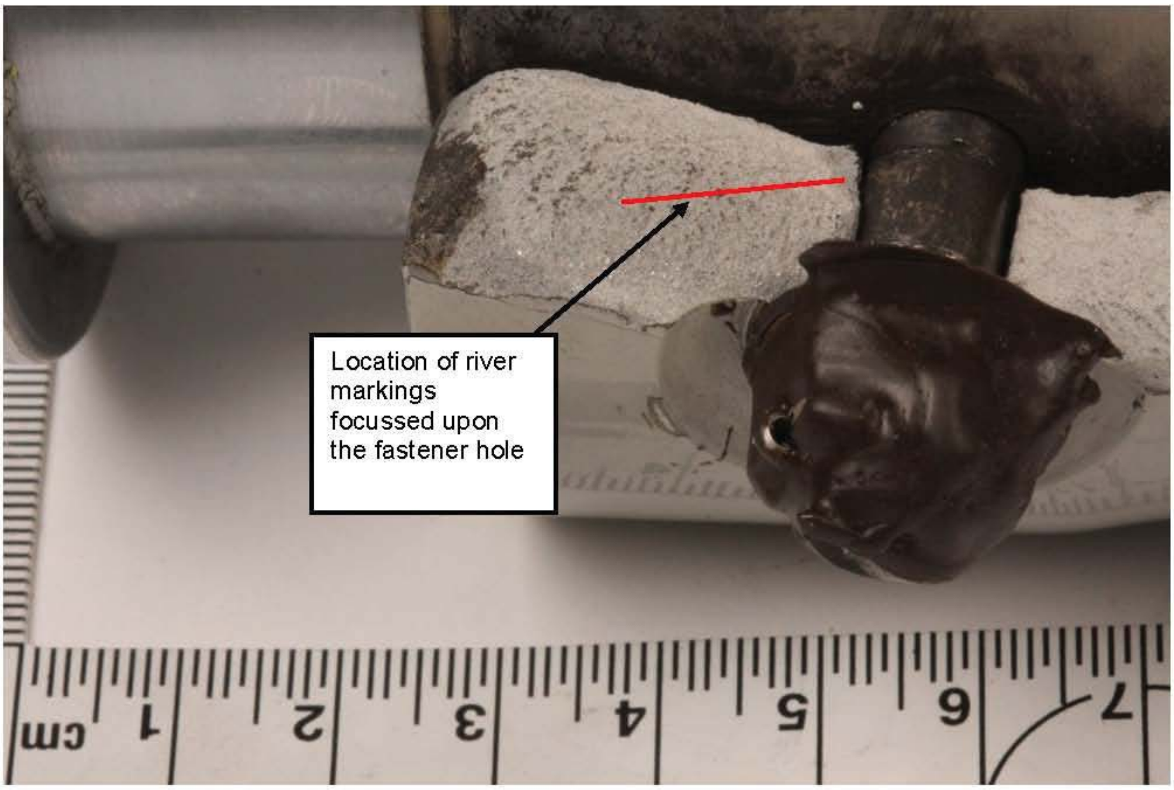

Figure 8: Showing the details of fracture surface 'A1'.

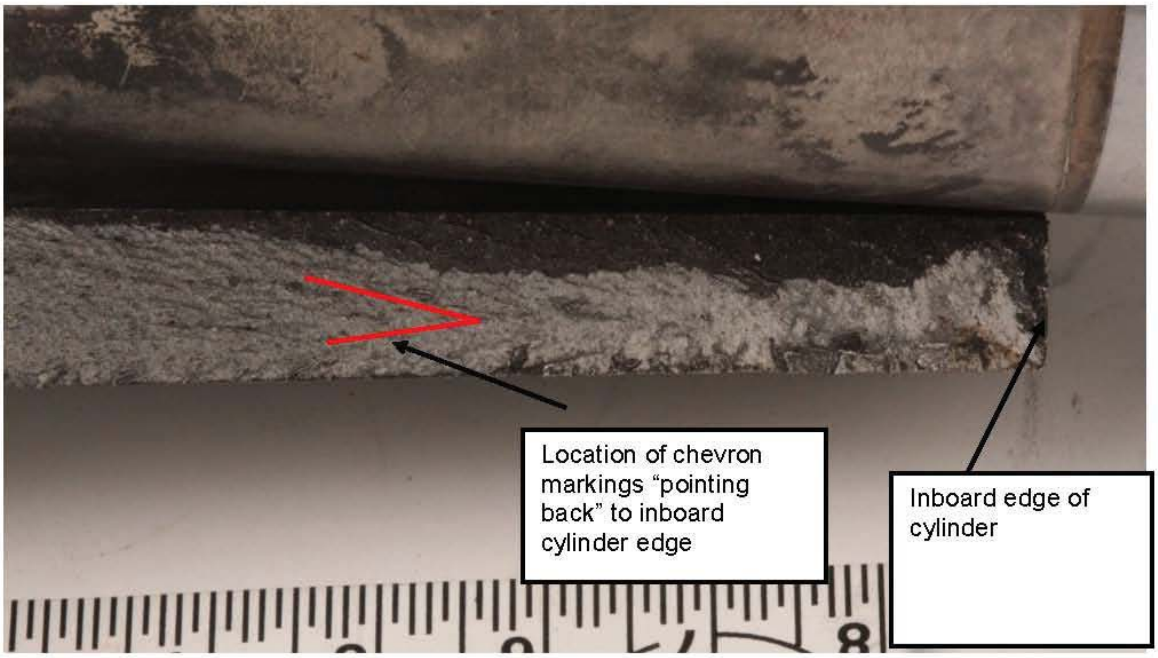

Figure 9: Showing the detail of fracture surface 'A2'.

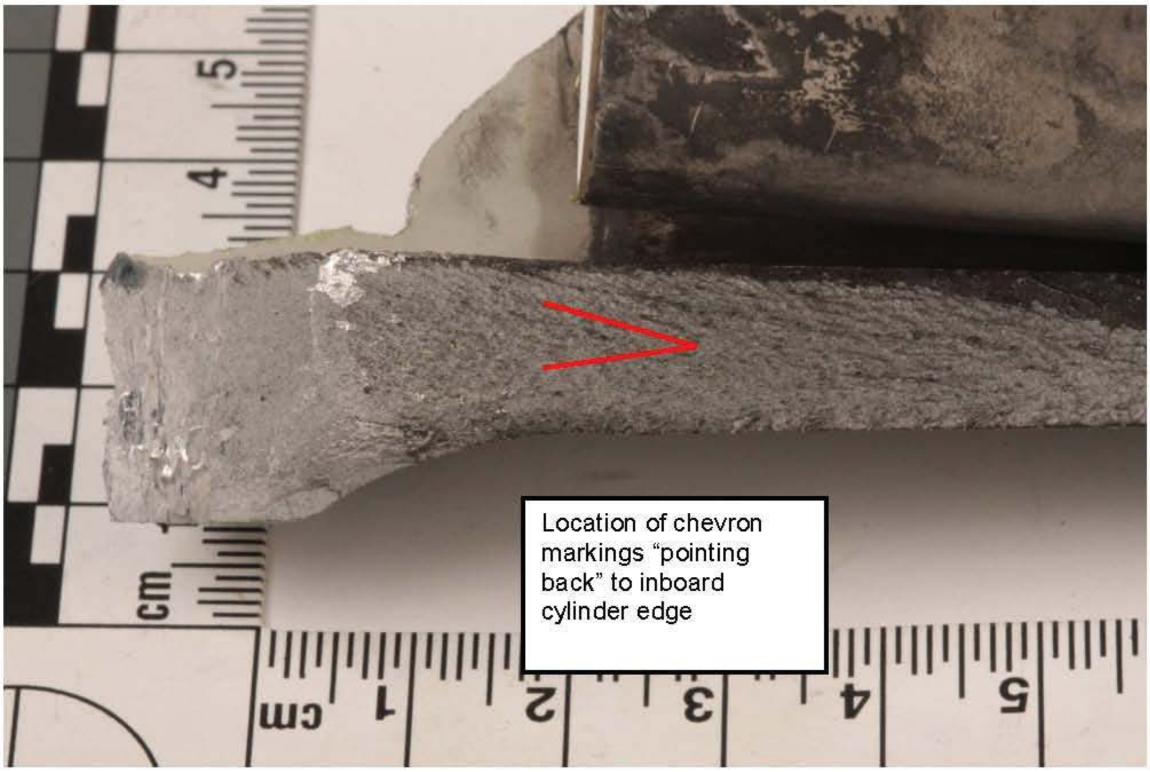

Figure 10: Showing the detail of fracture surface 'A2'.

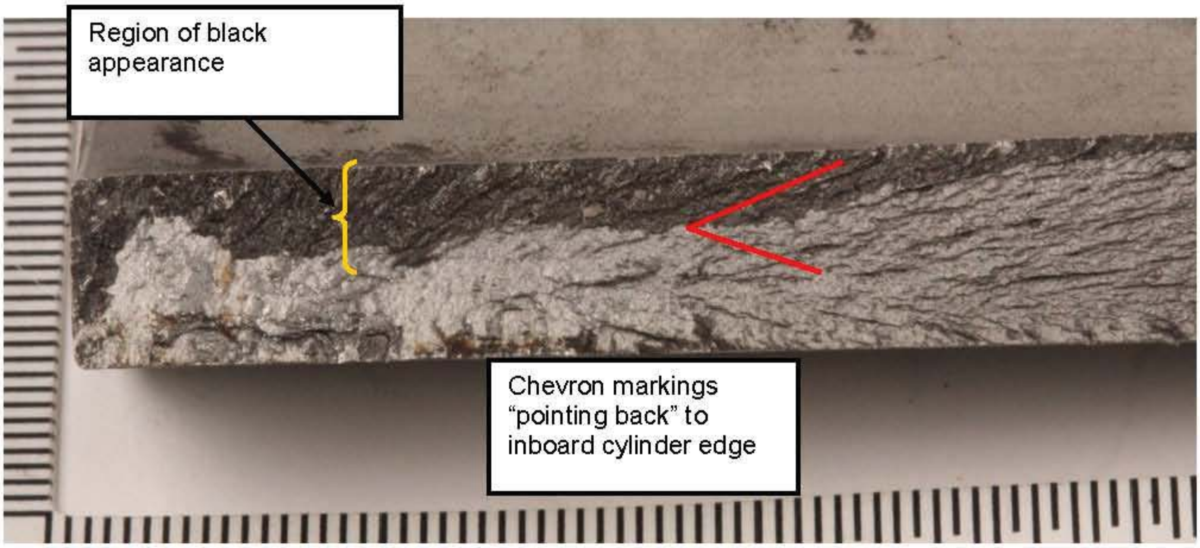

Figure 11: Showing the detail of fracture surface 'B2'.

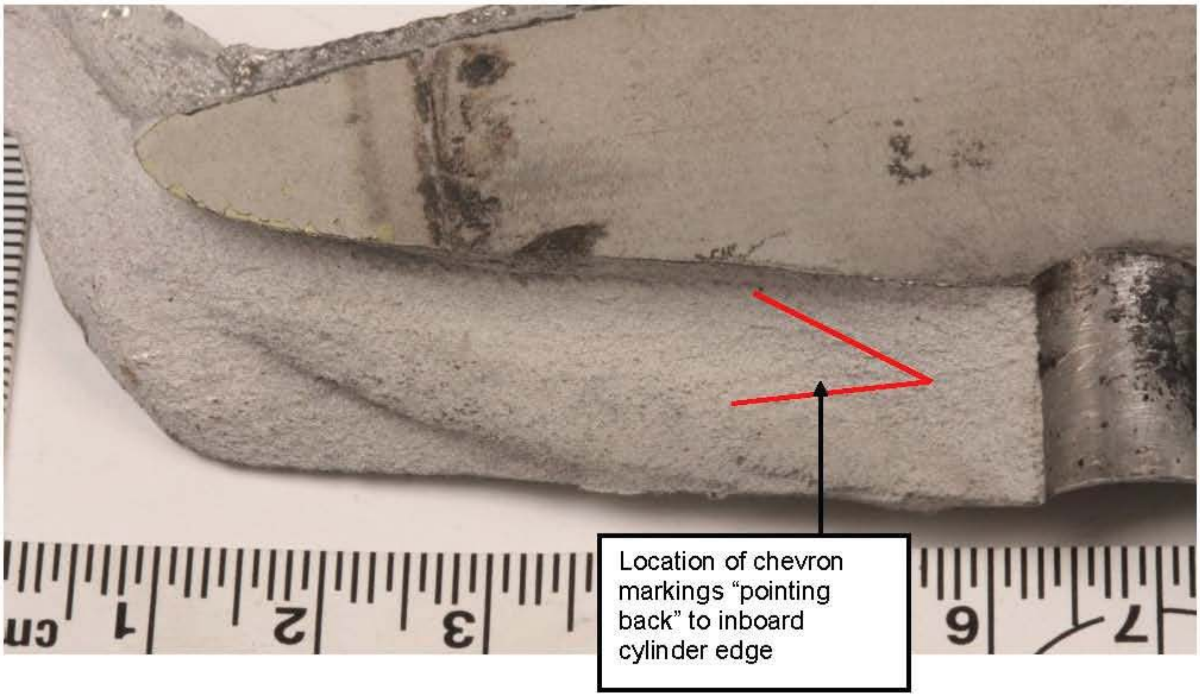

Figure 12: Showing the detail of fracture surface'B1'.

11

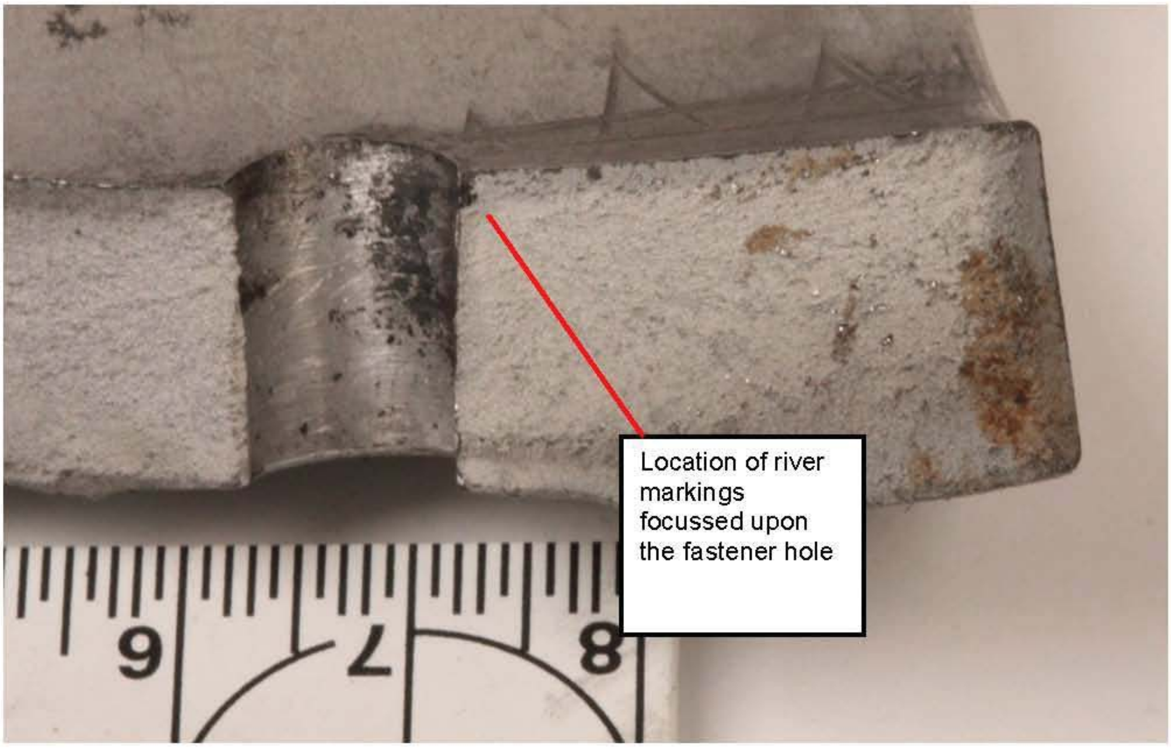

Figure 13: Showing the detail of fracture surface 'B1'.

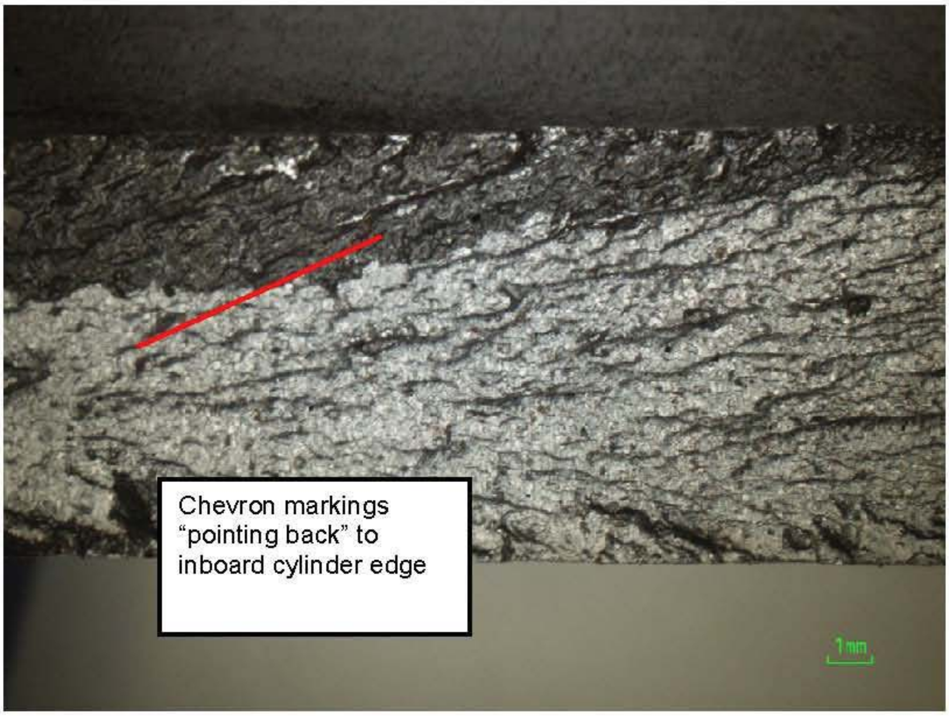

Figure 14: Showing the markings present upon fracture surface 'B2'.

12

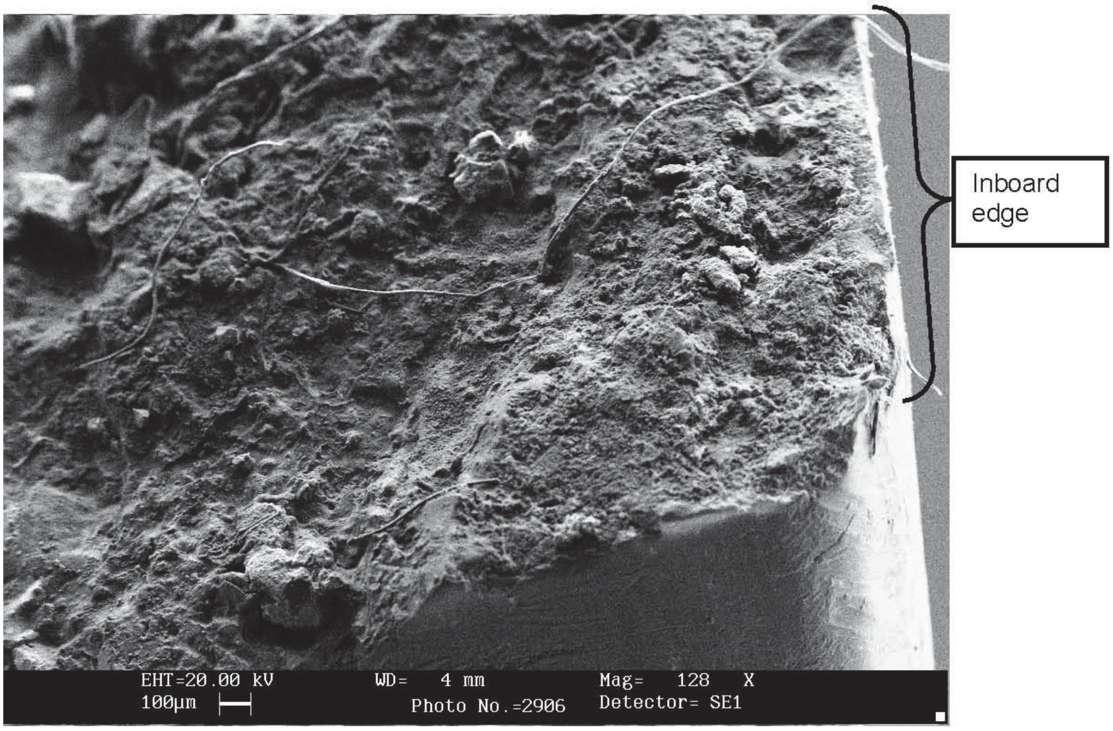

Figure 15: Scanning electron micrograph showing the smeared and corroded condition of the initiation site of the failure at the inboard edge of fracture surface 'B2'.

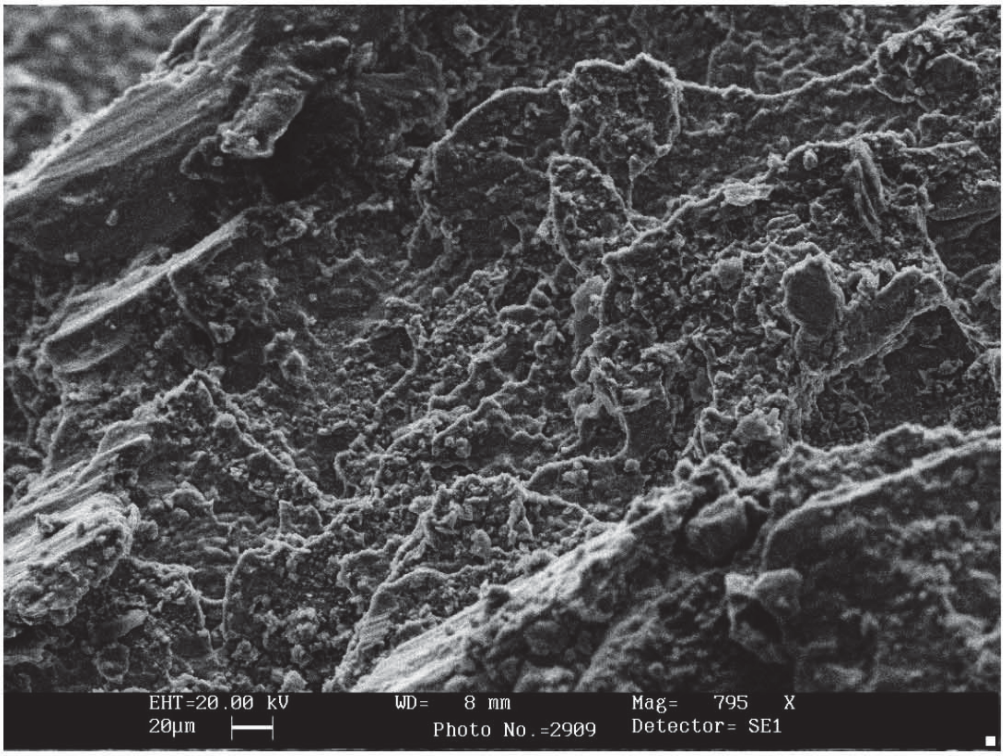

Figure 16: Scanning electron micrograph showing the features present upon the fracture surface consistent with post failure corrosion.

13

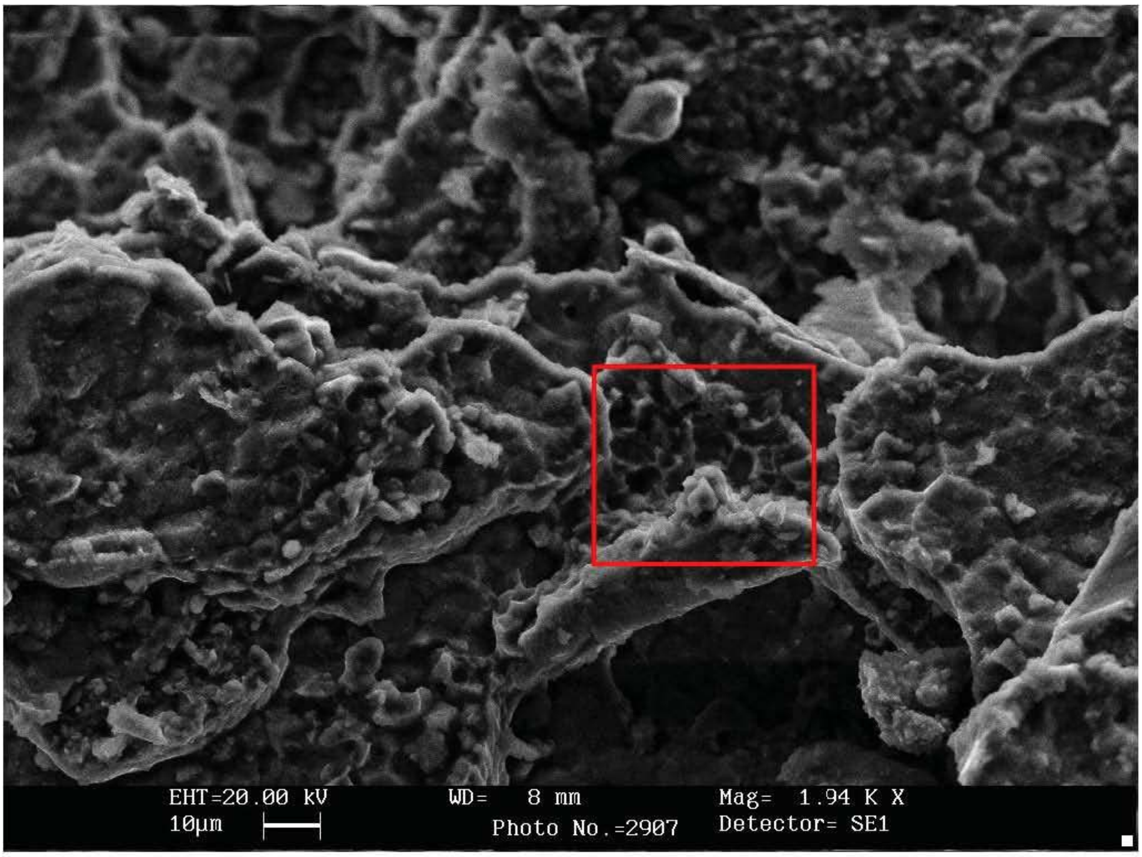

Figure 17: Scanning electron micrograph showing the features present upon the fracture surface consistent with ductile microvoid coalescence. Examples are shown within the red box.