

FINAL REPORT

**AIRBUS A320-231, REGISTRATION VT-ESF
LEFT HAND MAIN LANDING GEAR
BOGIE BEAM FRACTURE
AT SINGAPORE CHANGI AIRPORT
26 NOVEMBER 2005**

AIB/AAI/CAS.029

**Air Accident Investigation Bureau of Singapore
Ministry of Transport
Singapore**

29 July 2009

The Air Accident Investigation Bureau of Singapore

The Air Accident Investigation Bureau (AAIB) is the air accidents and incidents investigation authority in Singapore responsible to the Ministry of Transport. Its mission is to promote aviation safety through the conduct of independent and objective investigations into air accidents and incidents.

The AAIB conducts the investigations in accordance with the Singapore Air Navigation (Investigation of Accidents and Incidents) Order 2003 and Annex 13 to the Convention on International Civil Aviation, which governs how member States of the International Civil Aviation Organization (ICAO) conduct aircraft accident investigations internationally.

In carrying out the investigations, the AAIB will adhere to ICAO's stated objective, which is as follows:

"The sole objective of the investigation of an accident or incident shall be the prevention of accidents and incidents. It is not the purpose of this activity to apportion blame or liability."

SYNOPSIS

On 26 November 2005 at 2220 hrs, an Airbus 320 departing from Singapore Changi Airport suffered a fracture to the left hand main landing gear bogie beam while taxiing. The bogie beam was fractured at the centre of the bogie beam where the main landing gear strut was attached. The aircraft came to a stop on the taxiway. There were no injuries.

AIRCRAFT DETAILS

| | |
|----------------------------|---|
| Aircraft type | : Airbus A320-231 |
| Registration | : VT-ESF |
| Aircraft serial number | : MSN 432 |
| Number and type of engines | : 2 x V2500-A1 |
| Place | : Taxiway EP between Taxiways B2 and B3 Singapore Changi Airport |
| Date of occurrence | : 26 November 2005 |
| Local time of occurrence | : 10.20 p.m. |
| Type of flight | : Scheduled passenger |

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1 FACTUAL INFORMATION

All times used in this report are Singapore times. Singapore time is eight hours ahead of Coordinated Universal Time (UTC).

1.1 History of the flight

- 1.1.1 At 10.20 p.m. on 26 November 2005, an Airbus 320 departing from Singapore Changi Airport to Chennai suffered a fracture to the left hand main landing gear (MLG) bogie beam while taxiing on Taxiway EP. The aircraft came to a stop between taxiways B2 and B3 (see **Figure 1**). There were no injuries in this incident.



Figure 1: Left hand MLG bogie beam failure

1.2 Damages

- 1.2.1 The left hand MLG bogie beam fractured into two parts at the pivot pin attachment hole (see **Figures 2 and 3**).

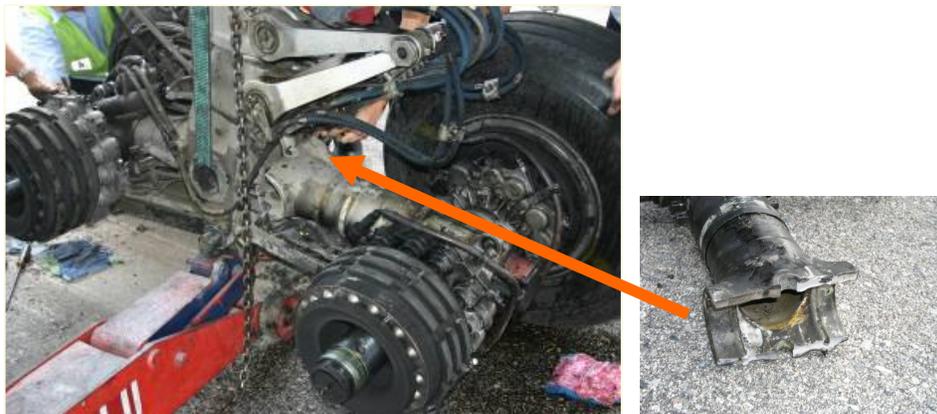


Figure 2: The bogie beam fractured into two parts at the level of the bogie pivot pin attachment hole.

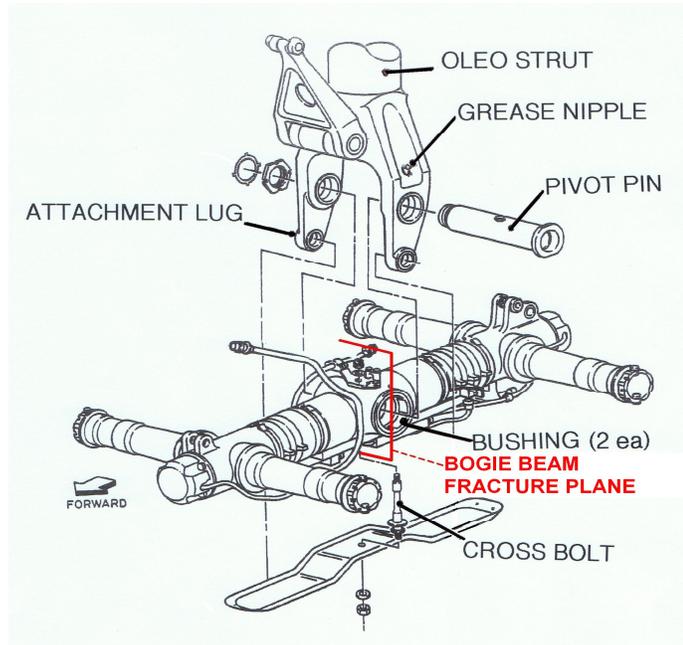


Figure 3: Bogie beam fracture plane

1.2.2 The left MLG oleo strut attachment lugs suffered scuffing from being dragged on the ground for about 50 metres before the aircraft came to a stop. The attachment lugs were found dug into the asphalt due to the weight of the aircraft (see **Figure 4**).



Figure 4: The left MLG oleo strut attachment lugs dug into the asphalt

1.2.4 The taxiway surface suffered gouges (over a distance of about 50 metres, with varying depths of between 1 and 2 cm) from Taxiway B2 to where the aircraft stopped (see **Figure 5**).



Figure 5: Gouging on Taxiway (about 50 metres)

1.3 Aircraft Information

1.3.1 Left Hand MLG history:

| | |
|------------------------------|-----------------|
| MLG Part Number (P/N) | : 201174079-010 |
| MLG Serial Number (S/N) | : DLG-0015 |
| Bogie beam and dressings P/N | : 201216015 |
| Bogie beam and dressings S/N | : B34 |
| Cycles since new (CSN) | : 21,170 |
| Cycles since overhaul | : 4,438 |

1.3.2 The left hand MLG (including the bogie beam and fittings) was initially fitted to another aircraft (MSN 431). During a routine inspection on 13 February 2003, the pivot pin was found to be cracked and two bushings were missing. The pivot pin and bushings were replaced and the aircraft was returned to service.

1.3.3 The left hand MLG was subsequently removed from aircraft MSN 431 and sent for overhaul in July 2003. (The CSN was then 16,732.) The overhaul involved a general visual inspection (without visual aids) of the MLG bogie beam for flaws (including deterioration of protective treatment, corrosion and cracks) before the protective coating and plating were removed. The bogie beam was magnetic particle inspected for flaws after the protective coating and plating were removed. The bogie beam was visually re-inspected (without visual aids) prior to re-protecting the bogie beam. After the overhaul, it was fitted to the incident aircraft (MSN 432).

1.3.4 The MLG bogie had four wheels. This four-wheel bogie construction is unique to the operator's fleet of A320 aircraft. Other operators' A320 aircraft have MLG with only two wheels and no bogie.

1.3.5 Initial on-site inspection found that the grease around the grease nipples on the left hand MLG bogie had dried up and was black in colour. Samples of the grease from various locations of the MLG bogie beam were collected and sent for testing.

1.4 **Flight Recorders**

1.4.1 The aircraft's cockpit voice recorder (CVR) and flight data recorder (FDR) were removed by the AAIB and brought to the Directorate General of Civil Aviation in India for download and readout.

1.4.2 Details of the CVR and FDR:

CVR:

Fairchild Solid State FA-2100 CVR

Part number: 2100-1020-02

Serial number: 01401

FDR:

Fairchild Solid State FA-2100 DFDR

Part number: 2100-4043-02

Serial Number: 000166692

1.4.3 The CVR was successfully read out with good quality recording. The FDR was also successfully read out.

1.5 **Tests and Research**

1.5.1 Examinations were conducted on the fractured bogie beam and grease samples to determine the mode of failure.

1.5.2 The grease samples were examined at Singapore Test Services Pte Ltd (STS). The examination revealed a high level of chromium¹ in the grease from the inboard pivot pin bushing. This indicates considerable wear in the pivot pin bushing contact area.

1.5.3 The two halves of the left hand MLG bogie beam were examined at three independent laboratories, viz. STS, Messier-Dowty Ltd (in Gloucester, UK) and EADS Centre Commun de Recherche (in Suresnes, France). Results of the examinations are in **Appendix A**. The key results are as follows:

- There were corrosion pits underneath the cadmium plating.
- The cause of the bogie beam fracture was the corrosion pits that had developed at the radius intersection of the bogie pivot pin bore and the cross bolt hole. At two locations at the bogie radius

¹ The pivot pin was chrome-plated.

intersection, fatigue cracks initiated and propagated from these corrosion pits (see **Figures 6 and 7**). Stress corrosion cracking finally led to the bogie fracture.

- The overhaul carried out in July 2003 for the bogie beam did not achieve the required cadmium plating minimum thickness at the cross bolt hole as required by the specifications. Investigation of the fractured bogie found corrosion pits underneath the protective paint and cadmium layers. However, cadmium thickness was not a factor in the corrosion development and in crack initiation.

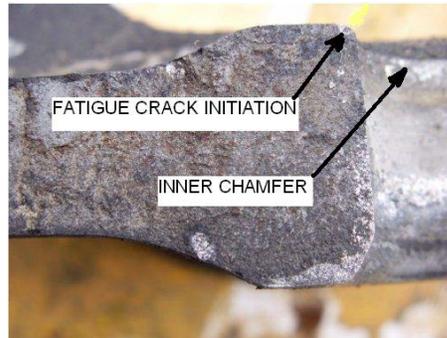


Figure 6: AFT-1

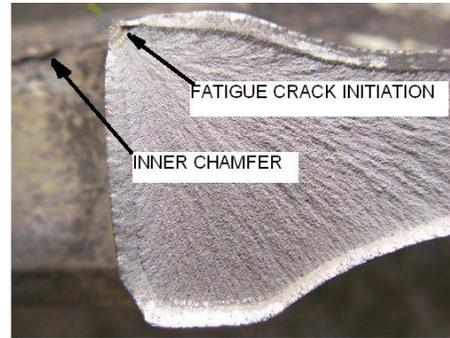


Figure 7: AFT-2

AFT-1 and AFT-2 surfaces showing evidence of fatigue crack initiation. (See paragraph 2.1 in Appendix A for the locations of AFT-1 and AFT-2.)

1.6 **Additional information**

- 1.6.1 The landing gear manufacturer performed a quality audit in January 2006 on the company who carried out the overhaul in July 2003. No major discrepancy was found regarding the non-destructive testing and the cadmium plating processes.

2 ANALYSIS

- 2.1 The left hand MLG pivot pin was found cracked and two bushings missing in February 2003. It could not be established whether this prior event had any impact on the bogie beam fracture.
- 2.2 The overhaul of the left hand MLG in July 2003 involved visually inspecting (without visual aids) the MLG components for flaws before the protective coating and plating were removed. These components were visually inspected (without visual aids) again after the protective coating and plating were removed. The post-incident discovery of corrosion pits underneath the cadmium plating indicates that the corrosion was present at the time of the overhaul but was not detected. The visual inspection carried out on the left hand MLG bogie beam was unlikely to be effective in detecting corrosion pitting underneath the protective coating and plating.
- 2.3 The cadmium plating carried out during the overhaul in July 2003 did not meet specification minimum thickness requirement at the bogie cross bolt hole. Although this was not a factor in the fracture of the bogie beam, the overhaul procedure did not ensure that the required plating minimum thickness was met at the cross bolt hole.
- 2.4 The wear of the pivot pin bushing contact area suggests a lack of lubrication. However, there is no evidence to suggest that the lack of lubrication contributed to the corrosion pitting.

3 CONCLUSION

From the evidence available, the following findings are made. These findings should not be read as apportioning blame or liability to any particular organisation or individual.

- 3.1 The cause of the bogie beam fracture was the corrosion pits that developed at the radius intersection of the bogie beam pivot pin bore and cross bolt hole. At two locations at the bogie radius intersection, fatigue cracks initiated and propagated from the corrosion pits. Stress corrosion cracking finally led to the fracture.
- 3.2 The corrosion pits were present at the time of the last overhaul in July 2003. Protective layers covered corrosion pits, both at the initiation sites and in the bogie radius intersection of the cross pin bore.
- 3.3 The cadmium plating carried out during the overhaul in July 2003 did not meet specification minimum thickness requirement at the bogie cross bolt hole. The overhaul procedure did not ensure that the required plating minimum thickness is met at the cross bolt hole.
- 3.4 There was a lack of lubrication at the pivot pin bushing contact area.

4 SAFETY ACTIONS

In the course of the investigation and arising from discussions with the investigation team, the parties involved have taken the following safety actions.

- 4.1 The operator of the aircraft performed a fleet-wide visual and non-destructive testing (NDT) inspection of its A320s' bogie beams. The inspection status and results are as follows:
- There are no cracks on the bogie beams inspected.
 - One MLG had to be replaced because the bogie beam had significant corrosion that could not be repaired on site.
 - The rest of the MLG bogie beams had only minor corrosions which were within acceptable limits and could be repaired on site.
- 4.2 The MLG manufacturer has since the incident amended the overhaul procedure to require removing the cadmium on the lower cross bolt hole, using a 10 times magnification lens for corrosion and crack detection during overhaul, and carrying out a magnetic particle inspection on the area to detect corrosion pitting.
- 4.3 The cadmium thickness applied at overhaul did not meet the specifications. The MLG manufacturer has since the incident, amended the overhaul procedure to require cadmium plating of the bogie cross bolt lower hole to the specification thickness and adhesion requirements.

5 **SAFETY RECOMMENDATION**

- 5.1 Although the lack of lubrication at the pivot pin bushing contact area may not have contributed to the bogie beam fracture, it is recommended that the operator should review its lubrication procedure for the bogie beam to ensure that the bushing contact area is adequately lubricated. (R-2009-006)

Examinations performed on the two halves of the left hand MLG bogie

1 Examination arrangement

1.1 The two halves of the left hand MLG bogie beam (see **Figure A1**) were examined at three laboratories, viz. Singapore Test Services Pte Ltd (STS) in Singapore, Messier-Dowty Ltd in Gloucester, UK, and EADS Centre Commun de Recherche (CCR) in Suresnes, France.

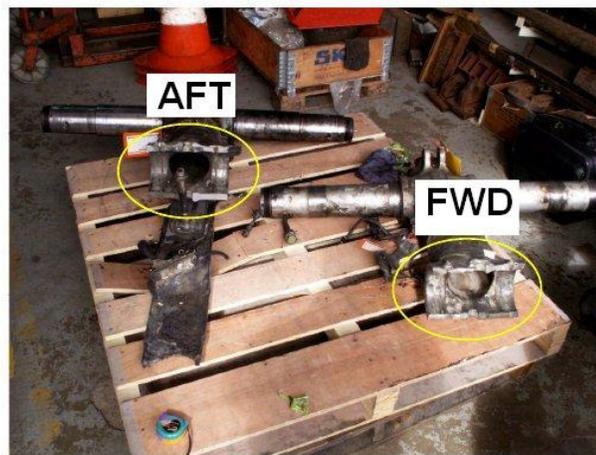


Figure A1: FWD and AFT bogie beam sections

1.2 The examinations performed at these laboratories were as follows:

| Test | STS | MD | CCR |
|--|-----|----|-----|
| Visual inspection | X | X | X |
| Dimension measurement | X | | |
| Fractography | X | X | |
| Energy Dispersive X-ray (EDX) analysis | X | | X |
| Metallographic examination | X | | |
| Hardness test | X | | |
| Chemical composition | X | | |
| Stress scan | | X | |
| Hydrogen analysis | | X | |
| Cadmium plating assessment | | X | X |
| Scanning Electron Microscope (SEM) | X | | X |
| Mark and striation examination | | | X |

2 STS examination results

2.1 At STS, tests were done on the aft half (AFT) of the left hand MLG bogie beam. The forward half (FWD) was preserved for further tests if

necessary. The fractured surfaces of the aft section were designated 'AFT-1', 'AFT-2', 'AFT-3' and 'AFT-4' (see **Figure A2**).

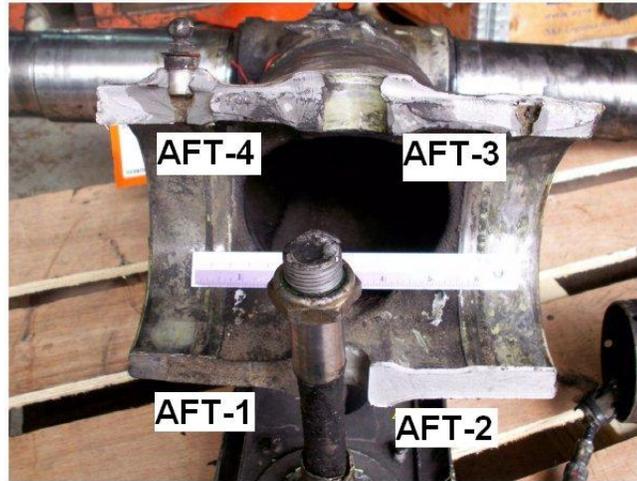


Figure A2: Designation of the aft fractured surfaces

2.2 Two fracture surfaces on AFT-1 and AFT-2 were cut off for fractographic examination.

2.3 Below is a summary of STS' findings:

- The chemical composition and hardness values were within the material specifications.
- Visual inspection of the fracture surface on the bogie beam found that AFT-1 was dull in appearance with signs of rusting. AFT-2, AFT-3 and AFT-4 appeared bright and fresh, with chevron marks and shear lips on the fracture surfaces. This indicates that delayed fracture might have occurred on AFT-1, whereas the rest were probably due to fast fracture. Fatigue fracture had originated from the chamfer of the bottom cross bolt hole.
- Although AFT-2 appeared bright and fresh, evidence of fatigue cracking was observed at the inner chamfer. Fatigue fracture had initiated from some corrosion pits (see **Figures A3** and **A4**).
- The thickness of the top coat (paint) and cadmium plating on the outer surface of the bogie beam were within the specifications (see **Figure A5**). But examination of the inner chamfer of the cross bolt bore revealed that thickness of the primer and cadmium plating were out of the specifications. Corrosion pits were observed on the inner chamfer. This may be due to moisture condensing on the surface.

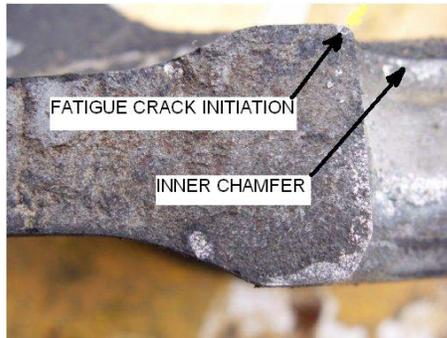


Figure A3: AFT-1

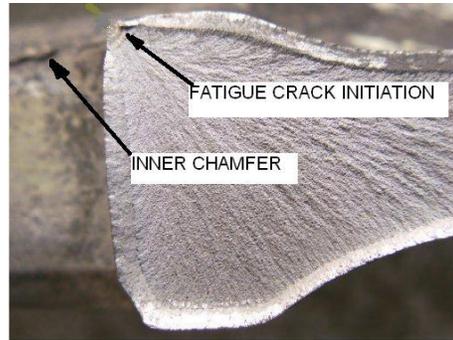


Figure A4: AFT-2

AFT-1 and AFT-2 surfaces showed evidence of fracture initiation.

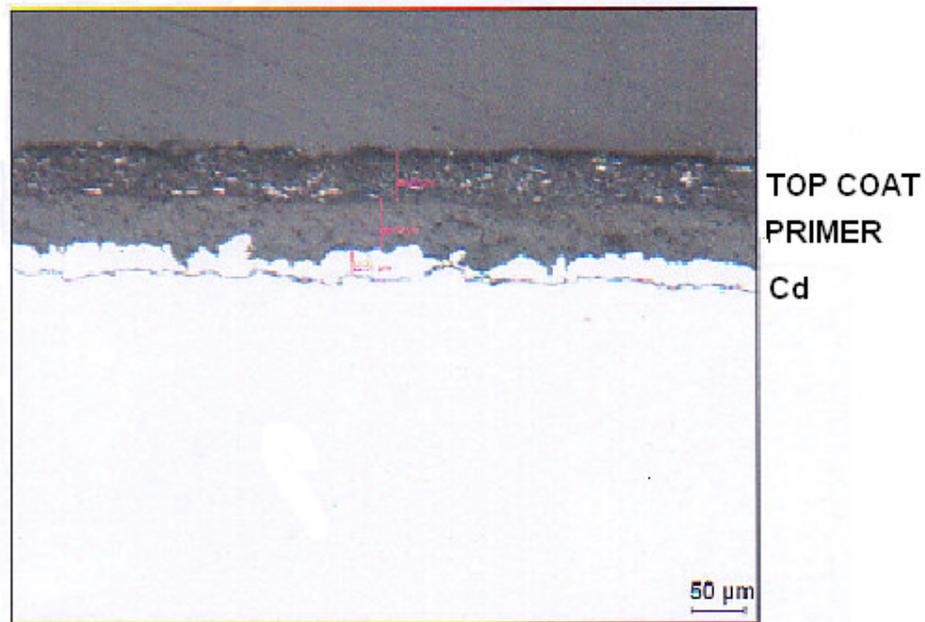


Figure A5: Micrograph showing the top coat, primer and cadmium plating.

2.4 Preliminary visual inspection revealed that the grease around the pivot pin bushings and on the bogie beam appeared to have dried up and was black in colour. Five grease samples were examined. The grease samples were taken from the following locations on the left hand MLG (see **Figure A6**):

- (A) Inboard grease nipple
- (B) Inboard pivot pin bore
- (C) Inboard pivot pin bushing inner groove
- (D) Inboard pivot pin bushing outer surface
- (E) Outboard grease nipple

The examination revealed a high level of chromium in the grease from the inboard pivot pin bushing inner groove. This indicates considerable wear in the bushing contact area.

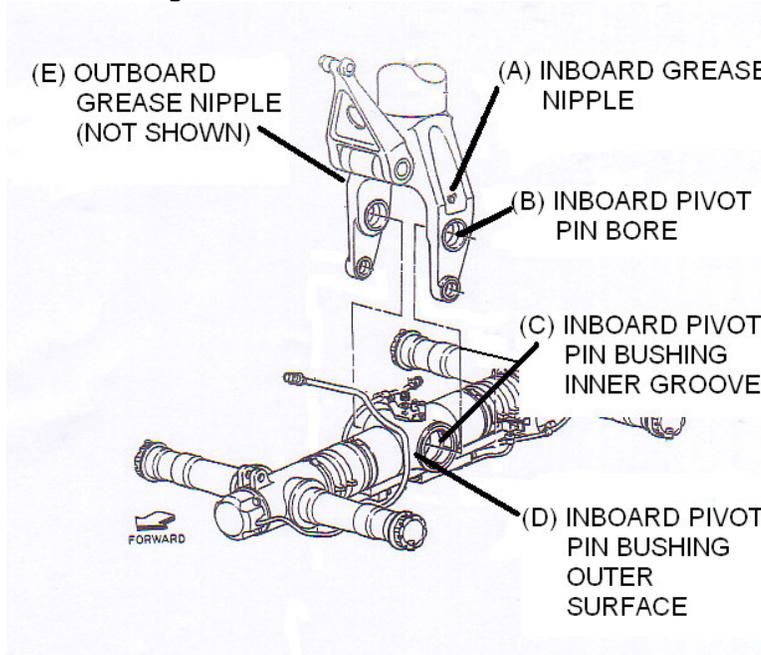
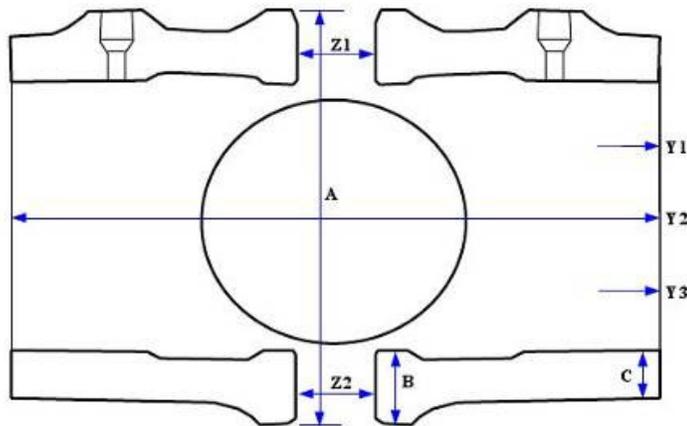


Figure A6: Bogie beam grease sample locations

2.5 The bogie beam dimension values were close to the specified values (see **Figure A7**).



| Measurement | Specification | Measured Value |
|-----------------------|---|--|
| Wall thickness at B = | 25 ± 0.5mm | 24.917mm |
| Wall Thickness at C = | - | 16.810mm |
| Internal Diameter Z = | 26 ± 0.021mm (standard rework \varnothing are also permitted, 26.2 and 26.4 with same tolerances) | 26.366mm (Z1) 26.051 mm (Z2) |
| Length of Bore Y = | 216 + 1.0mm | 217.164mm (Y1) 217.040mm (Y2) 217.050mm (Y3) |
| Height of A = | - | 160.309mm |

Figure A7: Bogie beam dimension values

3 **Messier-Dowty examination results**

3.1 The forward half of the bogie beam with the axle was sent to Messier-Dowty Ltd in Gloucester, UK for tests.

3.2 Below is a summary of Messier-Dowty's findings:

- Fractographic examination shows that the fracture of the bogie beam originated at the radius of the cross bolt hole and the pivot pin bore. Corrosion pitting was evident at this radius and in areas where the cadmium plating thickness was below specification or the cadmium was not present at all. The cadmium thickness was also shown to be below the specification in an undamaged area separate from the fracture. It can therefore be concluded that the under-specification cadmium thickness at the cross bolt hole radius was not wholly caused by sacrificial depletion, but by a lack of plating, although some sacrificial depletion is likely to have occurred during the operation of the part.
- Cadmium present at the cross bolt hole radius was found plated into the pits. This indicates that the corrosion pits were present at the time of the overhaul of the bogie beam in July 2003. This is confirmed by the primer being visible in the bottom of the pitting.
- It is known that during overhaul the visual inspection was carried out before the cadmium was stripped due to concerns about corrosion of the exposed steel should the cadmium have been removed. This may have contributed to the corrosion pitting remaining undetected.
- There is no evidence to indicate what caused the corrosion to originally occur. It is reasonable to assume that the corrosion protection in the area of the cross bolt hole radius failed.
- The corrosion pitting might have contributed to the initiation of fatigue fracture because a pit would act as a stress raiser.
- It is likely that the moisture that caused the corrosion pitting on the cross bolt hole radius migrated through the fatigue crack, thereby initiating the stress corrosion crack.
- The intergranular area of the lower inboard fracture would have been created relatively rapidly. After this intergranular propagation had occurred, it appears that the fracture did not propagate for a significant amount of time. This is indicated by the extent of the corrosion present on this part of the intergranular fracture surface. It is not possible to state a

definitive time period for this delay, although it should be noted that unprotected high strength alloy steel (the material used for the bogie beam) will corrode relatively quickly.

- The bogie beam, prior to its use on MSN 432 was in service on MSN 431 until July 2003. In February 2003 the MSN 431 bogie pin was subject to a laboratory investigation that concluded that damage to the pin was caused by the gear being operated with two pivot pin bushes being absent. The bogie beam might have accrued metallurgical damage through being operated without the pivot pin bushes. From the available evidence it cannot be concluded definitively that operation of this bogie beam with missing pivot pin bushes contributed to this failure.

4 **CCR examination results**

4.1 The AFT half of the bogie beam, previously sent to STS for examination, was sent to CCR for further examination.

4.2 Below is a summary of CCR's findings:

(a) For AFT-1:

- (1) Corrosion pits initiated at the inner chamfer. These corrosion pits date back to the overhaul period or sooner as they were covered by the protection layers at part refurbishing. They are due to lack of or defective cadmium protection layers.
- (2) Fatigue crack initiated and propagated from these corrosion pits. No initiation date can be given for this crack. The surface smoothness could indicate that it started a little bit sooner than AFT-2.
- (3) Crack growth mechanism changed from fatigue cracking to a stress corrosion cracking process (SCC) after about 1 mm of fatigue propagation.
- (4) Final ductile rupture occurred when the fracture toughness was reached after about 80 mm of SCC crack propagation.

(b) For AFT-2:

- (1) Corrosion pits initiated at the inner chamfer.
- (2) Fatigue crack initiated and propagated from these corrosion pits at a time close to (a)(2) above.
- (3) Final ductile rupture occurred when the fracture toughness was reached after about 2 mm of fatigue crack propagation.