ACCIDENT INVESTIGATION REPORT

AIRCRAFT ACCIDENT No. ACCID01/06

Issued on 12th August 2008

By

Civil Aviation Authority of Macao, China

Report on the accident to Airbus A321 during push back at

Macau International Airport on 4th March 2006

Content

Operator	: Air Macau Company Limited
Aircraft Type	: Airbus A321-231
Registration	: B-MAJ
Flight Number	: NX628
Place of Accident	: Macau International Airport Aircraft Stand B4
Latitude	: 2209.40N
Longitude	: 11334.47E
Date and Time	: 4th March 2006 at 0630 UTC (daylight)

SYNOPSIS

On 4th March 2006, Air Macau A321-231 registration no. B-MAJ was being pushed back using a tow bar and a tractor operated by Menzies Macau Airport Services. After the aircraft had been moved backward for approximately 4 meters, the tow bar head assembly broke up and the aircraft came to a sudden halt causing injuries to 2 cabin crewmembers and 1 passenger on board. The aircraft also sustained minor damage in the tow bar attachment. As the passenger sustained bone fracture and required hospitalization for more than 48 hours, it was classified as an accident. The Civil Aviation Authority – Macao, China (AACM) therefore conducted an investigation to the circumstances of the accident in accordance with AACM Aircraft Accident /Incident Investigation Procedure.

The investigation concluded that the operation of tractor and the mechanical structure of the tow bar are not the causal factor of this accident. The reason of the

jerk is not able to be determined according to the information available.

However, 2 safety recommendations have been raised in regard to cabin safety.

1. Factual Information

1.1. History of the Flight

On 4th March 2006, Air Macau A321-231 registration no. B-MAJ flight no. NX107 arrived at its home base Macau International Airport from Pudong (PVG) International Airport, Shanghai at 0538 UTC. The only defect reported by the pilot was one inoperative coffee maker in the FWD galley. After replacement of the coffee maker and refueling, the aircraft was ready to continue its service to Taipei International Airport (TPE) under flight no. NX628 with 178 passengers, 2 flight crewmembers and 5 cabin crewmembers on board.

At 0640 UTC, Menzies Ramp Operations staff has connected the tractor Model FMC B600 to the nose landing gear of the aircraft via a tow bar model Clyde 15F2284. At that time, Air Macau maintenance technician was performing the handset communication with the cockpit. The Pilot-in-command of NX628, confirmed aircraft ready for push back with aircraft nose facing north. After confirming parking brake released and confirmation with the captain, the Air Macau maintenance technician gave hand signal to tractor driver indicating commencement of push back. The accident happened after the aircraft had been moved backward for approximately 4 meters.

A female passenger on wheelchair, aged 60, was the last passenger getting on board NX628. After boarding completed and all doors closed for approximately 2 minutes, aircraft push back started. At that time, the aforementioned passenger was walking towards the FWD toilet. Suddenly, the aircraft jerked to a stop. She lost her balance and fell down. Two other cabin crewmembers working in the FWD galley area at that time also fell down during the jerk. The passenger ended up on the top of a cabin crewmember's legs hurting her back and feeling dizzy. Both of the cabin crewmember claimed having their back injured. One of them claimed that she could not move.

The passenger and the two cabin crewmembers were sent to Kiang Wu Hospital for medical check up. One of the cabin crew members was released from the hospital on the same day. The passenger sustained bone fracture on her spine and required hospitalization for more than 48 hours.

1.2. Injuries to Persons

	Crew	Passenger	Others
Fatal	0	0	0
Serious	0	1	0
Minor	0	0	2

1.3. Damage to Aircraft

The damage to aircraft is minor. The tow bar attachment fitting at the nose landing gear of the aircraft was damaged due to excessive loading. As a shock absorbent design feature of the fitting, two bolts connecting a tube in this fitting had broken and the tube was pushed inwards as shown in Figure 1.3.1 and 1.3.2.

Figure 1.3.1

Figure 1.3.2

After replacement of the fitting, the aircraft was dispatched to service.

1.4. Other Damage

Towbar no. RTB18 involved in this accident has sustained damage in its towbar head assembly and head-to-tube connector.

The tow bar involved in this accident is made by Clyde, model no. 15F2284 suitable for the use on A319/320/321. According to Menzies' record, this tow bar was received on Nov 1997.

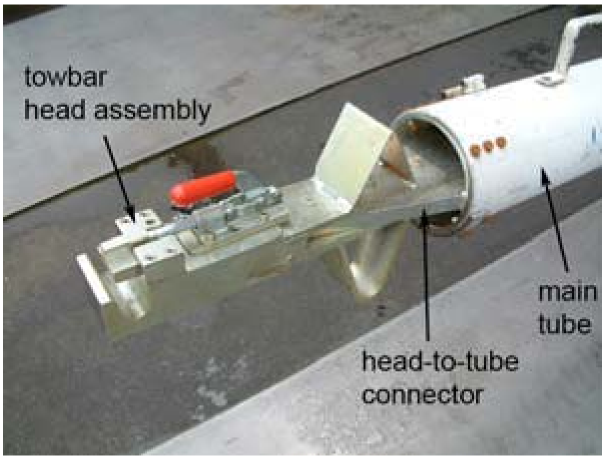


Figure 1.4.1

Figure 1.4.2

Figure 1.4.1 and 1.4.2 above shows a towbar of the same model. The towbar head assembly is attached to the main tube through the head–to-tube connector by three bolts. The bolts at the two ends were shear bolts. The middle one is fitted into a hole larger than a normal bolt hole, so that during operation, the shear load is transmitted through the two shear bolts. The middle bolt is of size of about 16 mm in diameter, and will take the shear load when the two shear bolt fail. The function of the shear bolts is to act as a safeguard against turning too abruptly, or at an angle which is too sharp during the pushback operation.

In this accident, all three bolts attaching the towbar head assembly to the head-to-tube connector were broken. As a result, the towbar head assembly liberated from the towbar. The upper plate of the head assembly, broken off from the main body near its welded joint, ended underneath the nose wheel. The lower plate was bent by almost 110^{o} and rested at the back of the nose wheel (as shown in Figure 1.4.3 to 1.4.6).

Figure 1.4.3

Figure 1.4.4

Figure 1.4.5

Figure 1.4.6

1.5. Personnel Information

1.5.1. Flight Crew

Pilot-in-Command: Male, aged 49

License: Macau, China ATPL(A)

Medical: Class One
Date of Exam 01/09/05
Valid until 13/03/06

Co-pilot: Male, aged 33

License: Macau, China CPL(A)

Medical: Class One
Date of Exam 25/08/05
Valid until 25/08/06

1.5.2. Cabin Crew

Chief Flight Attendant: Female, aged 27

Certificate: Macau, China Crew Member Certificate (CMC) valid until 31/12/06

Leading Flight Attendant: Female, aged 20

Certificate: Macau, China CMC valid until 11/08/06

Flight Attendant 3: Female, aged 24

Certificate: Macau, China CMC valid until 30/11/06

Flight Attendant 4: Female, aged 21

Certificate: Macau, China CMC valid until 30/04/07

Flight Attendant 5: Male, aged 23

Certificate: Macau, China CMC valid until 31/05/07

1.5.3. Operator of tractor

The operator of the tractor, has joined Menzies Macau Ariport Services since August 2001. According to Menzies, he is one of the most experience staff in ramp operation. His training is shown as follow:

Training	**Date Passed**	**Re-training**
Induction training		
Aviation Security	2-Sep-01	
Basic Ramp Operations	2-Sep-01	
Dangerous Goods Awareness	2-Sep-01	16-Aug-04
Manual Handling Operations	2-Sep-01	9-Dec-04
Ramp Safety	2-Sep-01	
Thunderstorm Warning Signals	2-Sep-01	21-Aug-03
Equipment training		
Tractor	2-Sep-01	
Belt Loader	2-Sep-01	10-Aug-03
Ground Power Unit	12-Sep-02	
Air Condition Unit	12-Sep-02	
Air Start Unit	12-Sep-02	
Cargo Loader	12-Sep-02	
Passenger Stair Truck	2-Jan-04	
Conventional Aircraft Tractor	2-Jan-04	
Fuel Truck	3-Jan-02	
Development Programme		
Telair International – B744 PDU & Inplane System	13-Mar-03	
Job responsibility and Communication	13-May-03	
Safety Alert Refresher Briefing 03	28-Oct-03	
Fire Safety Seminar	12-Jan-05	
MD11F Loading and Unloading Briefing	7-Apr-05	
BR Ramp OPS Awareness Campaign 05	12-Jul-05	

1.6. Aircraft Information

1.6.1. General

Manufacturer Airbus

Type	A321-231
Aircraft Serial No.	MSN 908
Year of Manufacturer	1998
Certificate of Registration	No. 1/99 issued on 4 Feb 1999 to Air Macau
Certificate of Airworthiness	No. 1/99 issued to Air Macau under Commercial Air Transport (passenger) Category
Engines	Two International Aero Engines V2533-A5
Maximum Take Off Weight	89000kg

1.6.2. Tow Tractor

The Model number of the tow tractor involved in the accident is FMC B600, designed to handle aircraft up to the B767 and A310. After the accident, Menzies continued to operate the tractor concerned for push back without any anomaly reported. Some of the maintenance tasks performed prior to the accident are shown as follow:

Date	Maintenance Task	Type
31 Jan 06	Rebuilt gear shifter	Defect rectification
13 Jan 06	Replace engine oil and filters, lubricate all areas, replace transmission fluid and adjust hand brake	Preventive maintenance
2 Jan 06	Replace new tires front	Defect rectification

1.6.3. Tow Bar

The tow bar involved in this accident is made by Clyde, model no. 15F2284 suitable for the use on A319/320/321. According to Menzies' record, this tow bar was received on Nov 1997.

Some of the maintenance tasks performed prior to the accident are shown as follow:

Date	Maintenance Task	Type
24 Dec 05	Perform PM	Preventive maintenance
9 Nov 05	Replace cable pin	Defect rectification
14 Oct 05	Perform 90 day inspection, replace shear bolts lube all areas, replace ball pin	Preventive maintenance

1.7. Meteorological Information

Meteorological report (METAR) at Macau International Airport near the time of accident was summarized as follows:

Report time:	0630 UTC
Surface Wind:	040º - 04 kt
Visibility:	8000 meters
Lowest Cloud:	few at 2000
Temperature:	16 ºC
Dew point:	10 ºC
QNH:	1017 hectopascals

1.8. Aids to Navigation

Not Applicable

1.9. ATC and Communications

The accident took place at parking stand B4 at Macau International Airport. After the boarding was completed and all doors were closed, NX628 received the pushback clearance from Macau Ground Frequency 121.725 MHz.

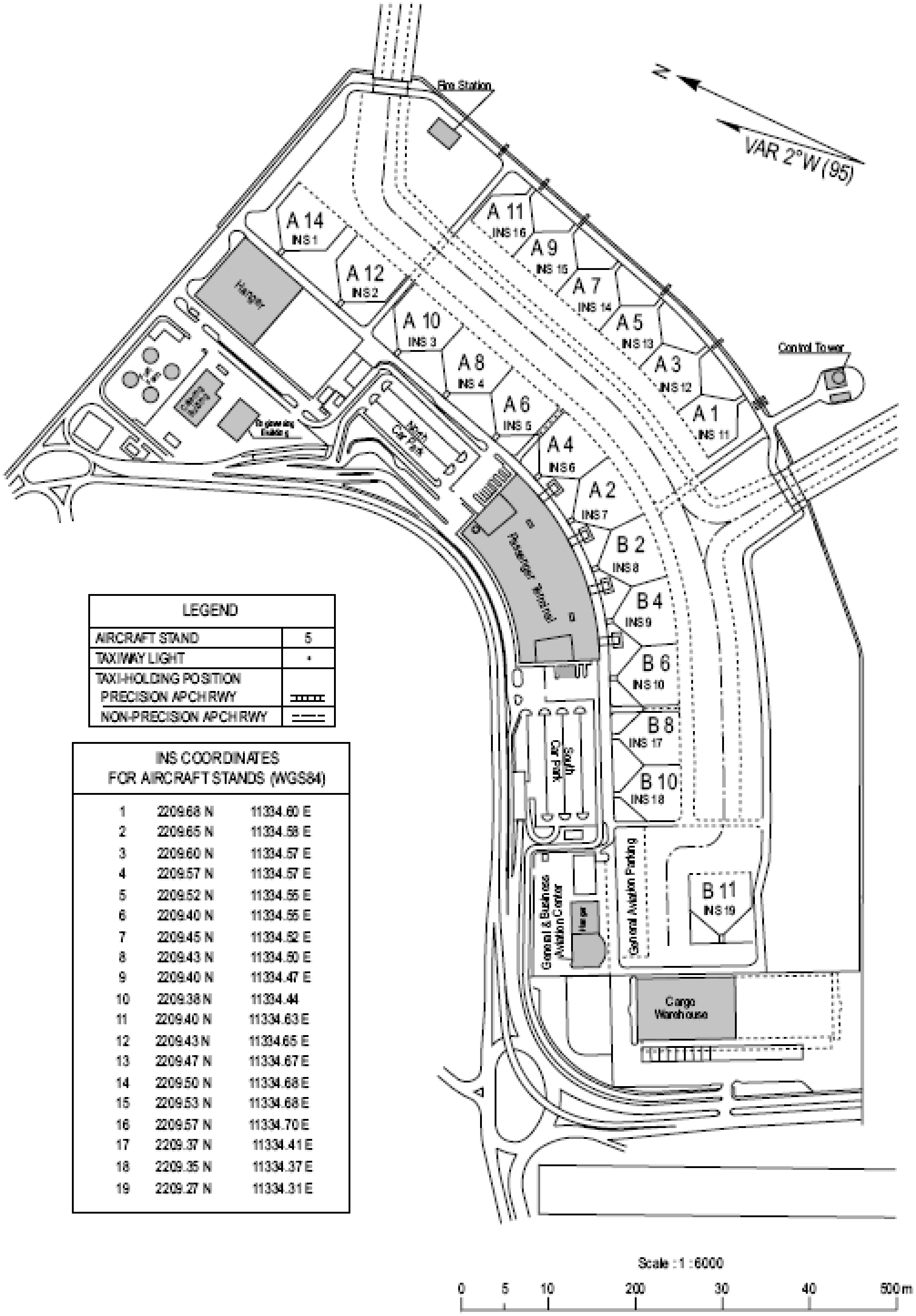
After the "Before Start checklist" completed, Pilot-in-Command of NX628 contacted the ground staff to start the pushback. According to the interviews of both pilots after the accident, the Pilot-in-Command released the parking brake and co-pilot confirmed the brake pressure check zero prior to the pushback commenced which in according with the company SOP.

After the aircraft was pushed back for several meters, the aircraft jerked. No engine was started or being started. The ground staff contacted the flight crew and requested to set the parking brake on. The ground staff informed the flight crew that the towbar was broken. The co-pilot informed Macau Ground that NX628 aborted the push back.

The Chief Flight Attendant informed the Pilot-in-Command that a passenger fell down in the cabin and was injured. The Pilot-in-Command reported the situation to Macau Ground and Air Macau Operation Control Center and requested medical assistance.

1.10. Aerodrome Information

Figure 1.10.1 depicts the aircraft stands schematic of Macau International Airport. Stand B4 is one of the four aircraft stands with loading bridge facility. After the accident, the apron surface was confirmed to be flat and undamaged. No foreign object was found in the vicinity of stand B4.



INS COORDINATES FOR AIRCRAFT STANDS (WGS84)

1	2209.68 N	11334.60 E
2	2209.65 N	11334.58 E
3	2209.60 N	11334.57 E
4	2209.57 N	11334.57 E
5	2209.52 N	11334.55 E
6	2209.40 N	11334.55 E
7	2209.45 N	11334.52 E
8	2209.43 N	11334.50 E
9	2209.40 N	11334.47 E
10	2209.38 N	11334.44
11	2209.40 N	11334.63 E
12	2209.43 N	11334.65 E
13	2209.47 N	11334.67 E
14	2209.50 N	11334.68 E
15	2209.53 N	11334.68 E
16	2209.57 N	11334.70 E
17	2209.37 N	11334.41 E
18	2209.35 N	11334.37 E
19	2209.27 N	11334.31 E

Figure 1.10.1

1.11. Flight Recorders

During the time of the accident, as both of the engines have not been started, all the recorders including flight data recorder, cockpit voice recorder and the QAR, were not recording.

1.12. Wreckage and Impact Information

Not Applicable

1.13. Medical and Pathological Information

Not Applicable

1.14. Fire

Not Applicable

1.15. Survival Aspects

Not Applicable

1.16. Test and Research

After the accident, the Civil Aviation Authority-Macao, China, has instructed Menzies Macau Airport Services to approach CityU Professional Services Ltd for metallurgical analysis of the damaged towbar. The study included a sit investigation, materials examination of the towbar head assembly material and the bolt material using a stereomicroscope and a scanning electron microscope(SEM). Tensile tests were also carried out to determine the tensile properties of the plates in the head assembly, and the material of bolts. The damaged towbar fitting from the aircraft and two new shear bolts were also provided for examination.

The report prepared by CityU Professional Services Ltd, dated 10 May 2006, concluded that :

a. The welded joint and the surrounding material in the towbar head assembly did not contain observable defects.

b. Sudden deceleration such as aircraft wheel braking provided a sudden force on the towbar. The large shear bolt was most likely shear failed due to this action.

c. The loss of the large shear bolt resulted in eccentricity of the towbar head, resulting in bending of the parallel plates of the towbar head assembly.

d. When the deformation in the top plate became large, the middle bolt of about 16mm in diameter was sheared to failure.

e. The top plate broke off from the head assembly when the local stress exceeded the ultimate tensile stress. The bottom plate continued to bend to its final shape.

f. When the towbar was brought to rest, the head assembly was nearly on the ground.

In the report, the force required to bend the towbar head assembly was calculated. Result of calculation shows that such excessive force is very unlikely to be attained by suddenly increase of power from the tractor. However, it is possible to attain such force by sudden deceleration from the aircraft side.

1.17. Organizational and management Information

1.17.1. Air Macau Company Limited

Air Macau Company Limited is a Macao based international airline operating to various cities in Mainland China and countries in South East Asia.

1.17.2. Menzies Macau Airport Services Limited

Menzies Macau Airport Services is a service provider of ground handling, cargo logistics, passenger handling, aircraft maintenance and aviation support services at the Macau International Airport.

1.18. Additional Information

Not Applicable

2. Analysis

2.1. Aircraft Airworthiness

All other aircraft systems, including aircraft brake system, were functioning properly.

2.2. Tractor Operation

The tractor driver was properly trained in terms of initial and recurrent training. After working in the ramp operation for more than 5 years, he is well-experienced on ramp operation and the equipment concerned. Both the tractor and the towbar concerned were properly maintained. As mentioned in Section 1.16, metallurgical analysis revealed that there was no observable defects on the towbar head assembly. It is also very unlikely that the force causing the breakage of the towbar can be attained by suddenly increase of power from the tractor. There was no evidence indicating tractor operation was a contributing factor to the accident.

2.3. Cause of towbar breakage

As one of the conclusion in the metallurgical analysis, breakage of the towbar was caused by sudden deceleration of the aircraft. The investigation team speculated there could be two possible scenarios causing such deceleration:

Scenario A - Accidental application of brake by pilot

During the push back operation, if the pilot applies aircraft brake or parking brake, it can bring the aircraft to a rapid deceleration. As indicated in the analysis report from CityU Professional Services Ltd., aircraft braking can cause an excessive force to the towbar resulting to a damage like in this event. Also, in the statement provided by the tractor driver, he emphasized that right after he noticed the breakage of the towbar, he found the parking brake indication light on the nose gear of the aircraft was on. The pilot statements assured that no brake or parking brake was applied until the ground staff requested to do so. However, it cannot be verified by QAR or FDR due to the fact that both were not activated before the engine start.

Scenario B. Foreign object blocking the aircraft in movement

There was also the possibility that certain foreign object, such as a wheel chock not properly removed prior to the push back operation, blocked one of the wheel and jammed the aircraft in movement to a sudden halt. Such foreign object could have been removed from the accident scene after the accident.

The investigation team has no sufficient information to conclude which of the above scenario is the causal factor of this accident.

2.4. Cabin safety during push back

While the aircraft is moving, cabin crewmembers and passengers not secured to their seats are exposed to risk of injury from sudden stops. The cabin crewmembers were standing in the cabin performing various duties when the aircraft was being pushed back. Two cabin crewmembers in the front galley area fell over and sustained minor injuries when the aircraft came to a sudden stop.

One passenger walking towards the front cabin toilet during the aircraft pushback fell over and sustained injuries and required hospitalization for more than 48 hours.

3. Conclusion

3.1. Rapid deceleration from the aircraft side resulting to an excessive force on the towbar caused the failure of the towbar. Cause of rapid deceleration of the aircraft cannot be determined in the investigation.

3.2. Due to the aircraft being pushed back came to a sudden halt, two cabin crewmembers and one passenger, who were not secured in their seats during that time, fell over and sustained injuries.

4. Safety Recommendations

Safety Recommendation 2006-01

During the aircraft surface movement, cabin crew members and passengers not secured to their seats are exposed to risk of injury from sudden stops. It is recommended that the aircraft operator

(i) review the cabin crew tasks and duties during aircraft surface movement and restrict their tasks to those directly related to safety only; and

(ii) review the operation policies and procedures to ensure that during aircraft surface movement, the cabin crewmembers are secured in their jump seats except when they have to perform any safety related duties.

Safety Recommendation 2006-02

It is recommended that the aircraft operator to review her operation policies and procedures to reinforce that the passengers are to be secured in their seats during the aircraft surface movement.

5. Appendices

Appendix A : Consultancy report from the CityU professional Services Ltd

CityU Professional Services Ltd

城大專業顧問有限公司

AN AFFILIATED COMPANY OF CITY UNIVERSITY OF HONG KONG

香港城市大學聯營公司

Consultancy Report

Name of Client:	Autoridade de Aviação Civil Região Administrativa Espeical de Macau
	Attn: Mr Brian C. W. Lai Head of Department Airworthiness
Address of Client:	R. Dr. Pedro José Lobo, 1-3 Edif. Luso Internacional, 26º andar Macau
Nature of Consultancy:	***Failure Analysis of a Towbar***
Report Prepared by:	Dr C M Lawrence Wu BSc(Eng), DMS, PhD, AMRAeS Associate Professor Department of Physics and Materials Science City University of Hong Kong
Date:	10 May 2006

1. Management Summary

On behalf of the Autoridade de Aviação Civil, Região Administrativa Espeical de Macau, Menzies Macau Airport Services Ltd. (Menzies) commissioned CityU Professional Services Limited (CPS) to study the cause of failure of an A320 towbar. The incident occurred on the 4th March 2006 at the Macau International Airport during the pushback of an Air Macau A321 aircraft. Apparently, after the aircraft was pushed back for a few metres, failure occurred in the towbar. At the end of the incident, one of the metal plates in the towbar head assembly was found to break near a welded joint and the other one was bent substantially. A few bolts were also found broken.

The study included a site investigation, and materials examination of the towbar head assembly material and the bolt material using a stereomicroscope and a scanning electron microscope (SEM). Tensile tests were also carried out to determine the tensile properties of the plates in the head assembly, and the material of a bolt of about 16 mm in diameter. The laboratory examination and test results were analysed, together with appropriate stress calculations.

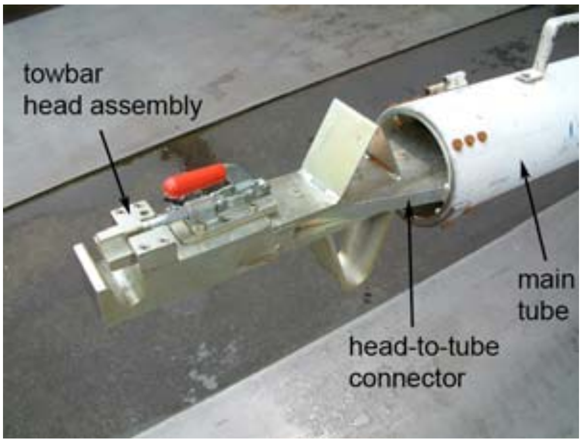
It was concluded that

a. The welded joint and the surrounding material in the towbar head assembly did not contain observable defects.
b. Sudden deceleration such as aircraft wheel braking provided a sudden force on the towbar. The large shear bolt was most likely shear failed due to this action.
c. The loss of the large shear bolt resulted in eccentricity of the towbar head, resulting in bending of the parallel plates of the towbar head assembly.
d. When the deformation in the top plate became large, the middle bolt of about 16 mm in diameter was sheared to failure.
e. The top plate broke off from the head assembly when the local stress exceeded the ultimate tensile stress. The bottom plate continued to bend to its final shape.
f. When the towbar was brought to rest, the head assembly was nearly on the ground.

2. Introduction

One of the services provided by the Menzies Macau Airport Services Ltd. (Menzies) at the Macau International Airport is aircraft transit arrangement, including push back of aircrafts. On 4th March 2006, an incident occurred at the Macau International Airport during the pushback of an Air Macau A321 aircraft. After the aircraft had been pushed back for a few metres, failure occurred in the towbar. At the end of the incident, one of the metal plates in the towbar head assembly was found to break near a welded joint and another plate was bent substantially. On behalf of the Autoridade de Aviação Civil, Região Administrativa Espeical de Macau, Menzies has commissioned CityU Professional Services Limited (CPS) to study the cause of failure of the A320 towbar. The towbar was manufactured by Clyde Machines.

Figure 2-1(a) shows a new head assembly of a towbar. One end of the head assembly consists of a U-channel with a half round shape at the bottom to receive the towbar fitting attached to the nose undercarriage. The other end consists of two parallel plates for connection to the head-to-tube assembly, which in turn connects to the main tube of the towbar with 12 bolts. The connection between the head assembly and the head-to-tube connector is with two shear bolts at either end, and a loosely fitted bolt of about 16 mm in diameter. This will be described in better details in Section 3. Figure 2-1(b) shows the towbar involved in the incident. In comparison with the new towbar head assembly, it can be seen that the top of the two parallel plates is broken off from the main body near its welded joint. Also, the bottom plate was bent by about 110°. Nearly all of the bolts attaching the locking mechanism on the top of the head assembly were broken.



(a) a new towbar head assembly


(b) incident towbar head assembly (plate on RHS came off near the top welding position)

Figure 2-1 : Appearance of incident towbar head assembly

3. Site Visit on 30 March 2006

A site visit was carried out on the 30 March 2006, with the support of Menzies. Representatives from the Airworthiness Department of the Autoridade de Aviação Civil of Macau also attended the site visit. During the sit visit, a number of observations were made, including:

a. Observation of a new Clyde A320 towbar for comparison with the incident one.
b. Initial inspection of the incident towbar.
c. Observation of a Clyde A320 towbar attached and pushed back an aircraft.

Figures 2-1(a) and 3-1 show the incident towbar fitted with a new head assembly. So although the head assembly and the head-to-tube connector were damaged, the remaining parts of the towbar were serviceable. In particular, the main tube and the positions for the bolts as shown in Figure 2-1(a) were in good condition, and so the fitting of a new head-to-tube connector and head assembly was possible. In other words, the damage to the towbar in this case was to the head-to-tube connector and head assembly only.

Figure 3-1 : The incident towbar fitted with a new head assembly

The results on the examination of the damaged head-to-tube connector and head assembly will be provided in a Section 4 of this report and will not be repeated here. During the site visit, the investigator requested to examine the towing fitting attached at the nose undercarriage, and Menzies was able to borrow it from Air Macau for examination. It was then found that both bolts connecting a tube in this fitting had broken, as shown in Figure 3-2. So this part was requested to be on loan from Air Macau for laboratory examination. A section of the bolt shank to nut connection was found, and was very likely from one of the two broken bolts. This was placed at the hole in Figure 3-2(a) for illustration.

(a) one side (b) other side

Figure 3-2 : Broken bolts attaching the tube in the towing fitting

A towbar attaching to the nose undercarriage of an A321 aircraft is shown in Figure 3-3. The details of attachment between the nose undercarriage and the towbar head assembly are shown in Figure 3-4. In particular, the towing fitting attached to the nose undercarriage contained a tube for quick connection to the towbar, and was locked into position during operation. It is noted that at this moment the other end of the towbar (with an eye) had not been attached to the tractor.

Figure 3-3 : A towbar attaching to the nose undercarriage of an A321 aircraft

Figure 3-4 : Details of nose undercarriage to towbar head assembly attachment

Figure 3-5 shows that the attachment between the head assembly and the main tube of the towbar was by three bolts. The bolts at the two ends were shear bolts. The middle one is fitted into a hole larger than a normal bolthole, so that during operation, the shear load is transmitted through the two shear bolts. The middle bolt is of size of about 16 mm (5/8-inch) in diameter, and will take the shear load when the two shear bolt fail. In particular, the shear bolts act as safeguard against turning too abruptly, or at an angle which is too sharp during the pushback operation.

Figure 3-5 : The wheels on towbar were retracted up after attaching towbar to tractor

Just before the pushback, the other end of the towbar was attached to the tractor. The wheels on the towbar were then retracted up, as shown in Figure 3-6.

Figure 3-6 : The wheels on towbar were retracted up after attaching towbar to tractor

A number of measurements of the towbar were made. These are shown in Figure 3-7.

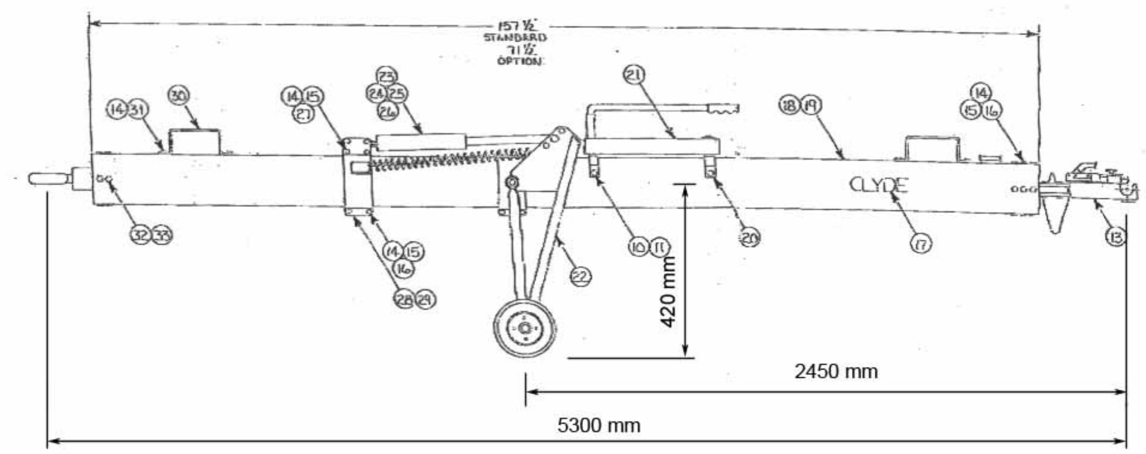


Figure 3-7 : Measurements of towbar (wheel is 130 mm above ground when retracted)

4. Initial Examination

The samples, having been identified during the site visit, were transported to the investigator at City University of Hong Kong for detail examination. Figure 4-1 shows the samples as received from Menzies. Apart from the pieces from the head assembly, the samples also consist of the towbar fitting on loan from Air Macau and the head-to-tube connector. Two new shear bolts were also provided for comparison. It is noted that at a later stage, three bolts of about 16 mm (5/8-inch) in diameter were also provided by Menzies for tensile test.

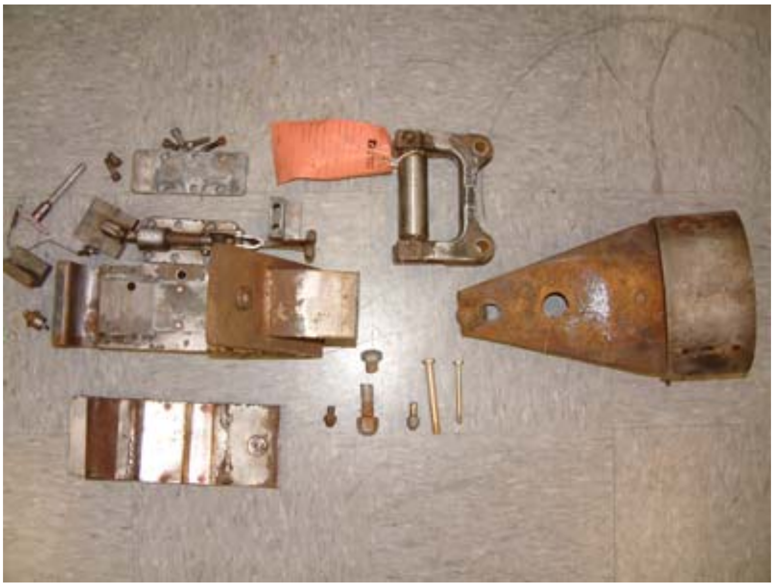


Figure 4-1 : Samples as received from Menzies

Figure 4-2(a) shows that the tip on the left-hand side of the plate of the head-to-tube connector was bent upwards. This is shown more clearly in Figure 4-2(b), in which a straight red lie was drawn to show that the plate was bent. A bushing at this position was also seen to rotate clockwise.

(a) front view

(b) bent tip and rotated bushing

Figure 4-2 : Appearance of head-to-tube connector

Figure 4-3(a) shows the top view of the head-to-tube connector. The positions for the shear bolts are indicated with red arrows. The remains of the shear bolt on the right-hand side (RHS) can still be seen. Figure 4-3(b) shows the rotated bushing as seen in Figure 4-2(b). The other shear bolt, originally installed through the centre hole of the bushing, was broken and its remains can be seen in this figure. This shear bolt has a smaller diameter than that on the RHS. The middle hole seen in Figure 4-3(a) provides a loose fit for the bolt of about 16 mm diameter, as shown in Figure 3-5. Under close examination, the RHS of the hole wall was found to have dented near the top surface. This shows that a large shear force was applied at this position on the bolt of about 16 mm in diameter.

(a) top view

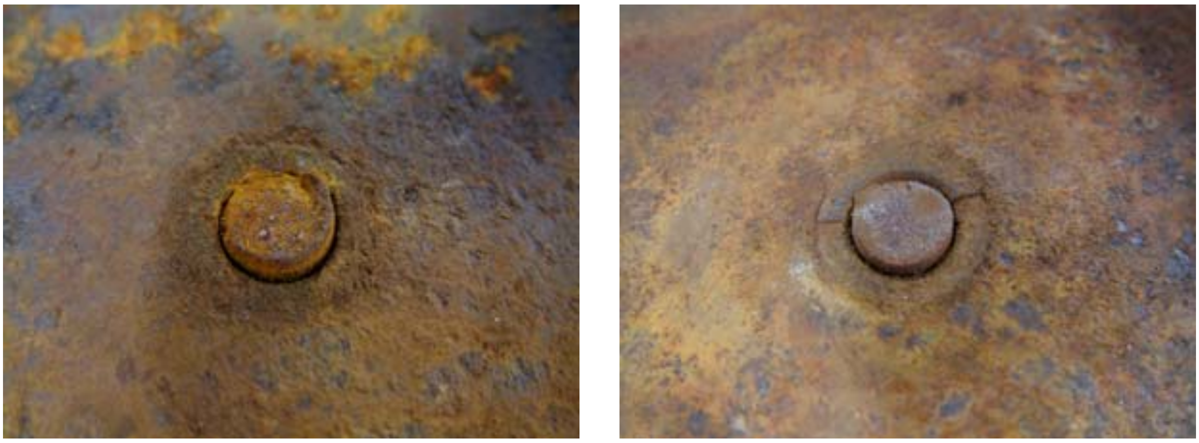
(b) bushing moved forward

Figure 4-3 : Top view of head-to-tube connector

Figure 4-4 : RHS of hole wall dented near top surface

It is clear that the large shear bolt was cleanly sheared off at the top and bottom surface positions of the plate in head-to-tube connector. This is because the fracture surfaces on the top and bottom surfaces are very flat, as shown in Figures 4-5(a) and 4-5(b) respectively.

As shown in Figure 4-3(b), the small shear bolt went through the centre of a bushing, which can be slid along a groove. So when the shearing action occurred, the small shear bolt was likely not shear-failed straight away. Instead, the bushing was pushed toward the main tube of the towbar. Due to the interaction between the head-to-tube connector and the bottom plate of the head assembly, as will be explained later, the small shear bolt was later pulled and sheared to the shape as shown in Figures 4-6(a) and 4-6(b). Also, the bent appearance of the shear bolt suggests that a large force existed to shear the bottom plate of the head assembly and the head-to-tube connector apart. As the two parts were not clamped together, the section of the shear bolt originally residing in the bottom plate of the head assembly was pulled out and bent. It was also seen in Figures 4-6(a) and 4-6(b) that large deformation occurred in the groove, as well as a part of the bushing broken off, indicating a large force involved.



(a) on top surface

(b) on bottom surface

Figure 4-5 : Large shear bolt fracture surfaces

(a) view showing broken side of bushing

(b) view showing highly deformed groove

Figure 4-6 : Small shear bolt fracture surfaces

Figure 4-7 shows the damaged head assembly. The top plate, which has the appearance as shown in Figure 4-8(a), broke off. Figure 4-8(b) indicates that the top plate was subjected to bending in the orientation as shown before fracture.

Figure 4-7 : Damaged head assembly

(a) Top plate broken off from head assembly

(b) Top plate bent before broken off

Figure 4-8 : Plates in head assembly broken and bent

The fracture surface on the broken off top plate is shown in Figure 4-9. It can be seen that the bottom part of the fracture surface contained tensile fracture as well as signs of bending, causing the appearance of layer separation. Figure 4-10 is the other part of the fracture surface, i.e. the one at the head assembly end. It is noted that the bottom plate was sawn off near the welded joint so as to reveal the fracture surface easily. Apart from having a fracture surface similar to that in Figure 4-9, this figure also contains evidence that the middle part, as well as the fracture surface, were subjected to indentation from a certain object. This will be explained later.

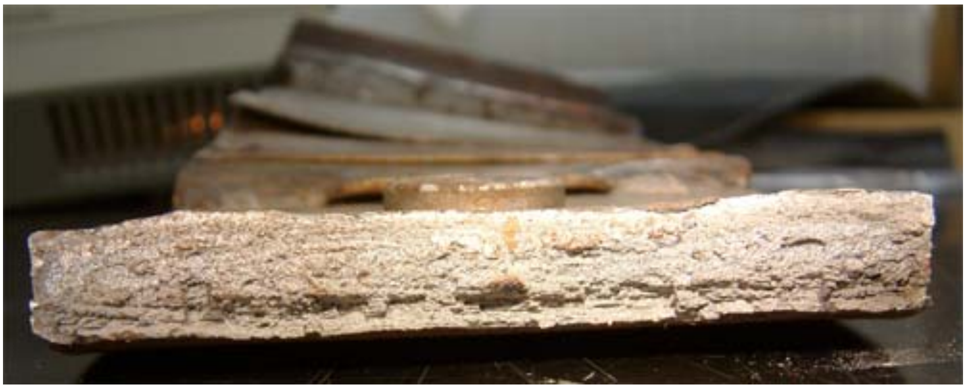


Figure 4-9 : Fracture surface of top plate

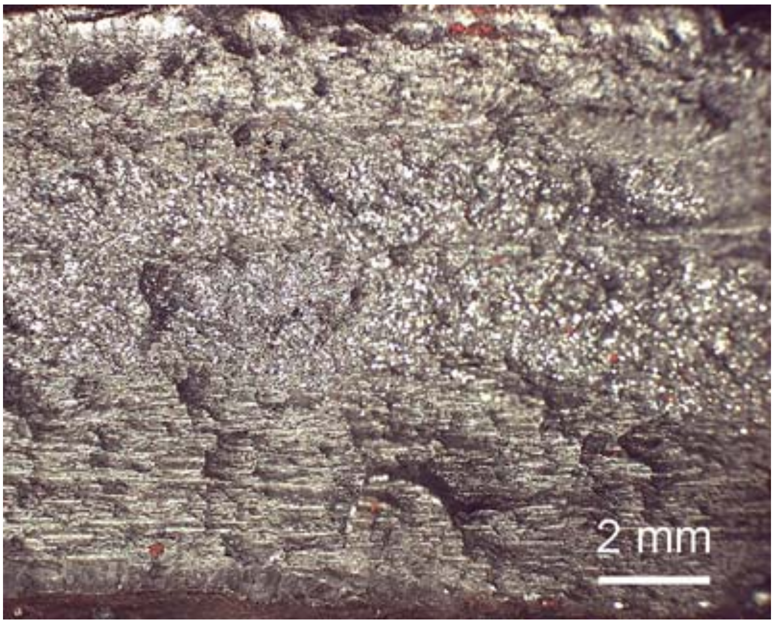


Figure 4-10 : Fracture surface of top plate at head assembly end

Figure 4-11 : Fracture surface of top plate at head assembly end

Figure 4-12 shows the curved section of the bottom plate. Some rub marks were found, and were correlated to the parts at the tip section of the head-to-tube connector.

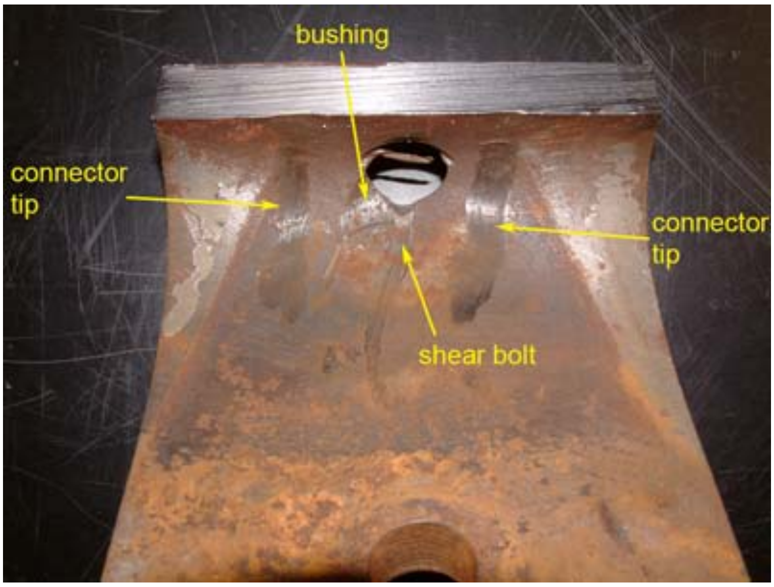


Figure 4-12 : Bent bottom plate with rub marks caused by parts of the head-to-tube connector

Figure 4-13 shows the bottom surface and end of the head assembly. A number of indentation marks as marked in red arrows were identified.

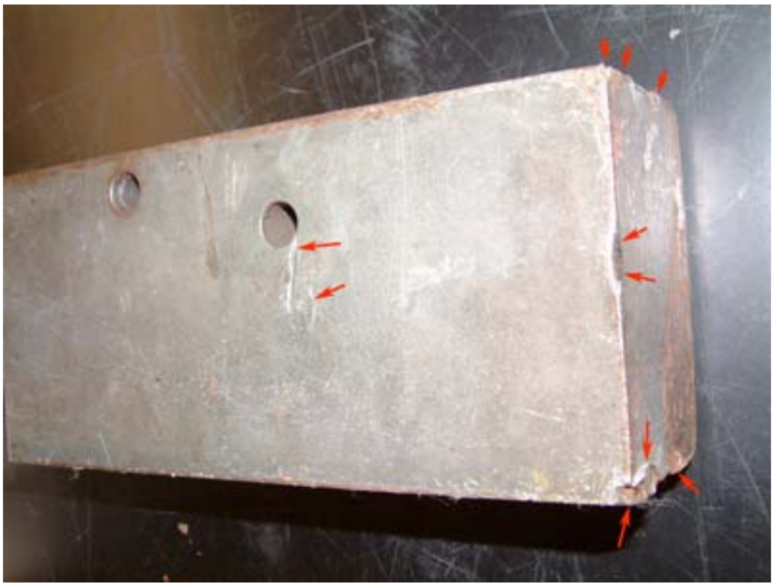


Figure 4-13 : Bottom surface of the metal block of the head assembly with indentation marks

The broken bolts of about 16 mm in diameter were then examined. It can be seen in Figure 4-14 that fracture occurred at the interface position between the top plate of the head assembly and the plate of the head-to-tube connector. The fracture surfaces of this bolt are shown in Figure 4-14. The fracture surface were very flat, and contained evidence that they were shear fractured. Figure 4-15 illustrates that fracture occurred between the top plate and the head-to-tube connector.

(a) Bolt broken in two

(b) Fracture surfaces of broken bolt

Figure 4-14 : Broken bolt of about 16 mm in diameter

Figure 4-15 : Lower part of the broken bolt (about 16 mm dia.)
illustrating fracture between top plate and head-to-tube connector

Figure 4-16 shows new large and small shear bolts, as well as the remains of the shear bolts from the incident.

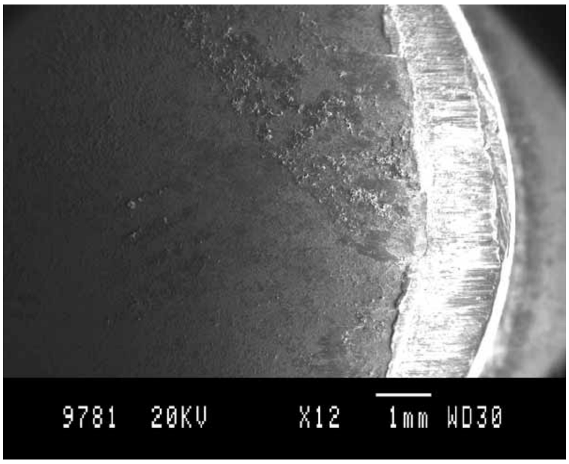
Figure 4-16 : Large and small shear bolts

Figure 4-17 shows the fracture surface of the large shear bolt. It can be seen that he fracture surface is very flat.

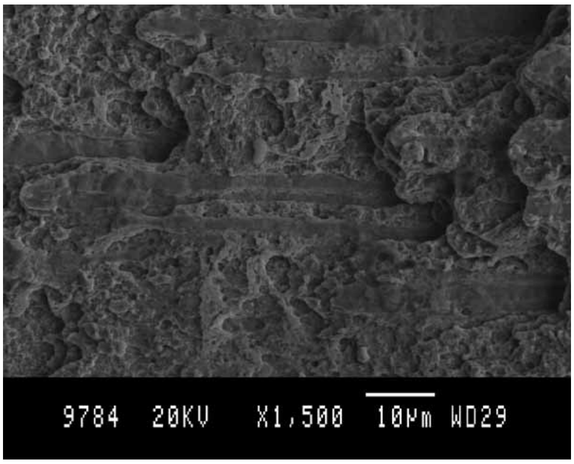
Figure 4-17 : Fracture surface of large shear bolt

5. Examination with Scanning Electron Microscope (SEM)

Examination with scanning electron microscope (SEM) was employed to study the bolt material and the welded joints of the head assembly to confirm their integrity. Figure 5-1 shows the fracture surface of the bolt of about 16 mm in diameter (shown in Figure 4-14(b) before). Figure 5-1(a) is a low magnification micrograph, showing the bolt was sheared from left to right. Figure 5-1(b) is a high magnification micrograph, confirming that shearing of the bolt was from left to right.



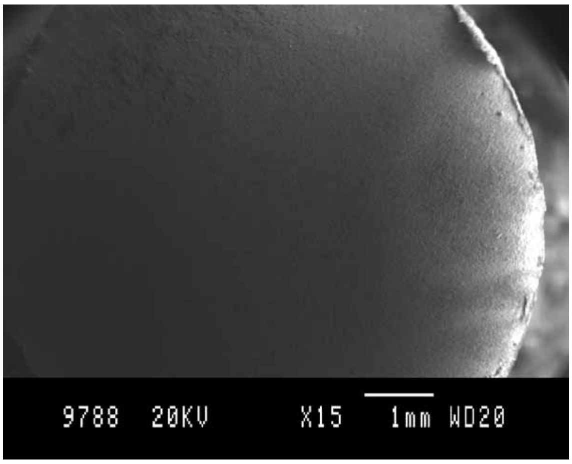
(a) Low magnification



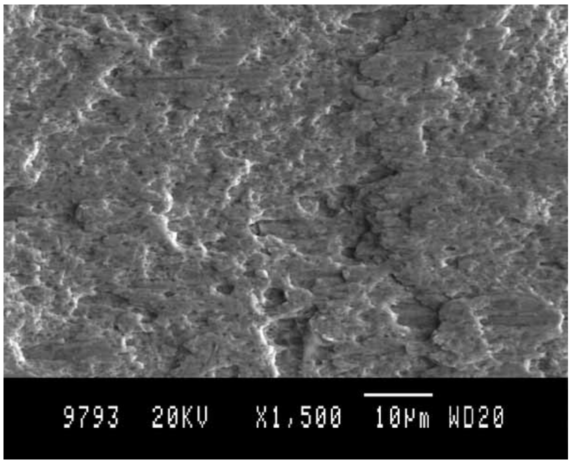
(b) High magnification

Figure 5-1 : SEM fractographs of bolt of about 16 mm diameter

Figure 5-2 shows the fracture surface of the large shear bolt shown in Figure 4-17 before. Figure 5-2(a) is a low magnification micrograph. Figure 5-2(b) is a high magnification micrograph, confirming that shearing of the bolt was from left to right. This material is seen to be softer than that of the bolt in Figure 5-1.



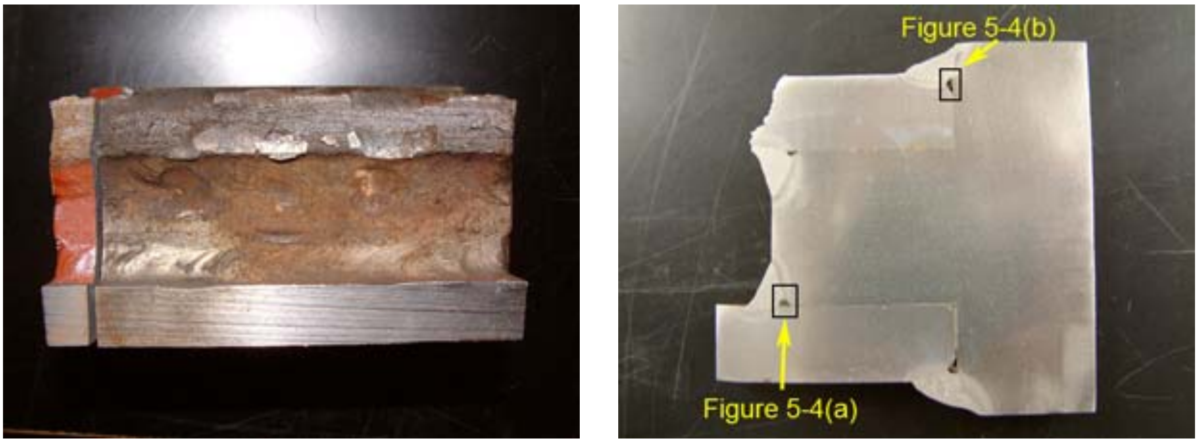
(a) Low magnification



(b) High magnification

Figure 5-2 : SEM fractographs of large shear bolt

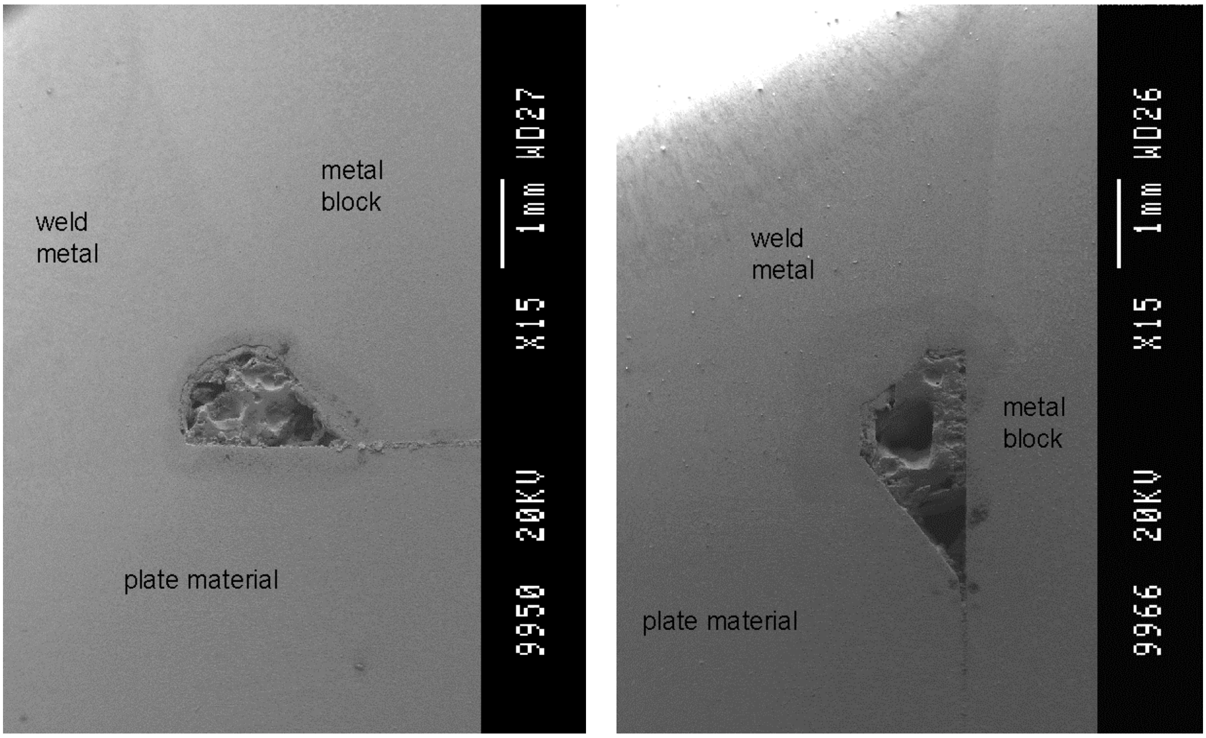
The head assembly is made from a metal block, welded with two horizontal plates. The welded joint of the head assembly was first sectioned at an appropriate location, as shown in Figure 5-3(a). Grinding, polishing and etching were carried out as shown in Figure 5-3(b), so as to reveal the microstructure. Figures 5-4(a) and 5-4(b) show typical microstructures at welded joints. They both show good weld interfaces between weld metal and metal block or plate.



(a) slice on the LHS for examination

(b) polished and etched surface

Figure 5-3 : Cross-section sample for examination of welded joints



(a) bottom LH weld

(b) top RH weld

Figure 5-4 : SEM micrographs of welded joints

Figures 5-5, 5-6 and 5-7 show the microstructures of the weld metal, block metal and plate metal respectively. It can be seen that the plate material is relatively soft. However, the microstructure of the three types of material are in good order.

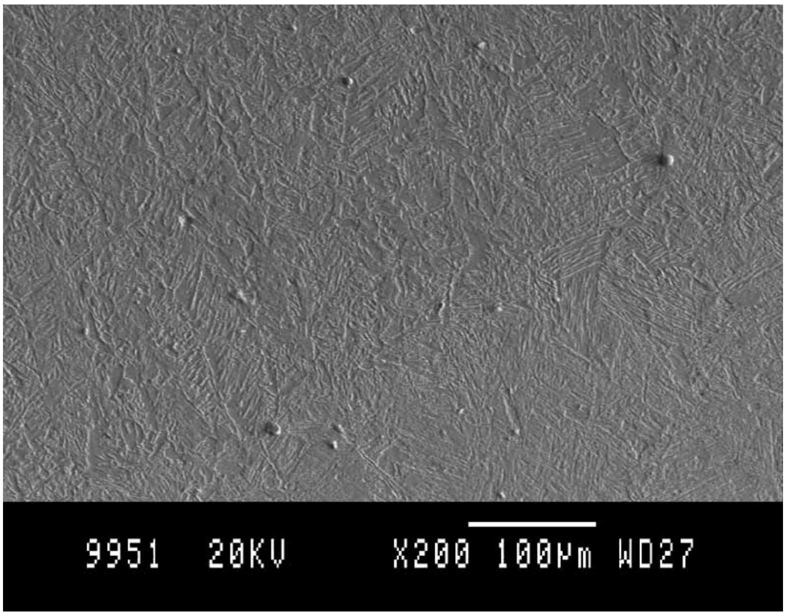


Figure 5-5 : Microstructure of welded metal

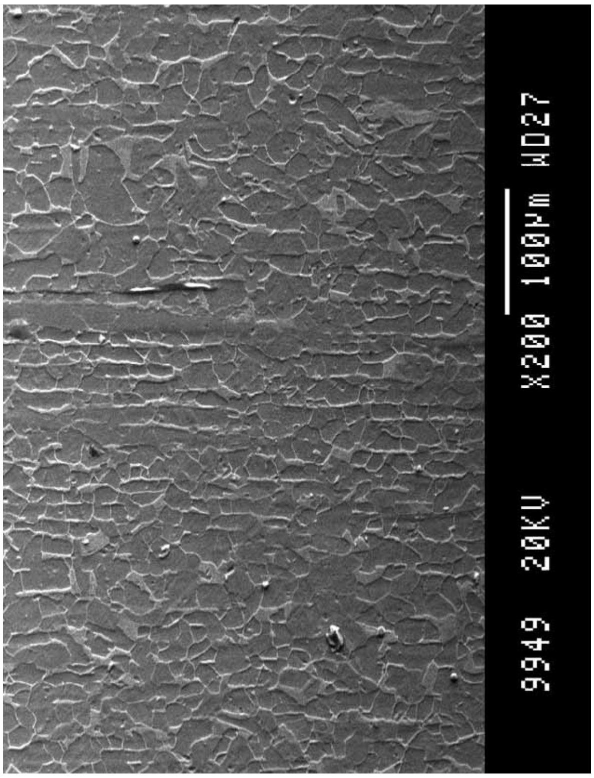


Figure 5-6 : Microstructure of block metal

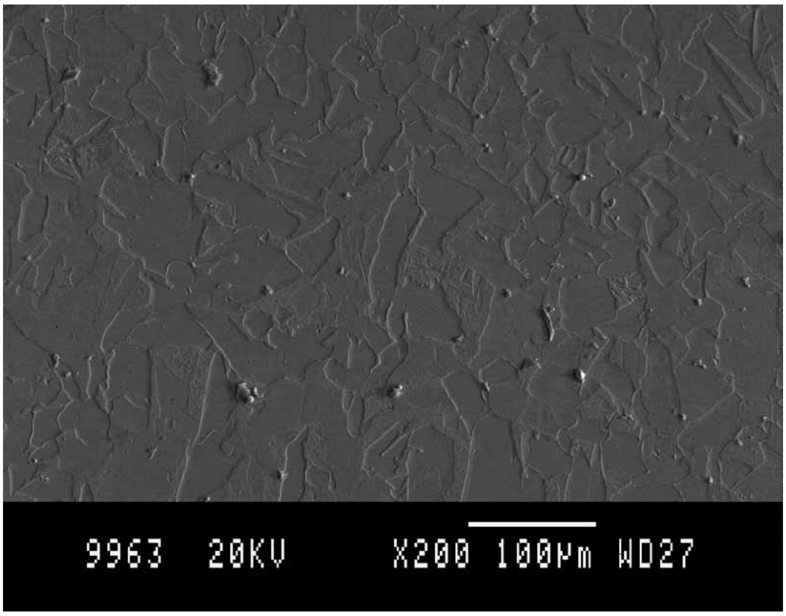


Figure 5-7 : Microstructure of plate metal

6. Tensile Tests

In order to obtain the tensile strength of the bolt and the plate materials, tensile test were carried out as per EN10002 Part 1. Tensile specimens with circular cross-section of about 3.8 mm in diameter at the gauge length were manufactured from the bolt or plate material. The results of the tensile test are shown in Tables 6-1 and 6-2 for the bolt and plate material, respectively.

Table 6-1 : Tensile test results of material of bolt of about 16 mm diameter

Sample	**Ultimate tensile stress (MPa)**	**Yield stress (MPa)**	**Elongation (%)**
1	953	857	12.0
2	965	870	12.8
3	943	832	14.4
Average	**954**	**853**	**13**

Table 6-2 : Tensile test results of plate material

Sample	**Ultimate tensile stress (MPa)**	**Yield stress (MPa)**	**Elongation (%)**
1	434	274	25.6
2	432	283	38.4
3	437	321	36.4
Average	**434**	**293**	**33**

7. Analysis

According to the information given to the investigator, the pushback was carried out as normal for about 5 m, then suddenly the towbar head broke. The above examinations have indicated how the parts in the towbar head assembly were related to each other during the incident. Figure 7-1 is a mock-up of the final positions of the relevant parts when the towbar came to a rest. Then, by further relating the head assembly with the main remaining parts of the towbar, the towbar position in relation to the undercarriage can be determined, and is shown in Figure 7-2.

Figure 7-1 : Final resting position of towbar head assembly

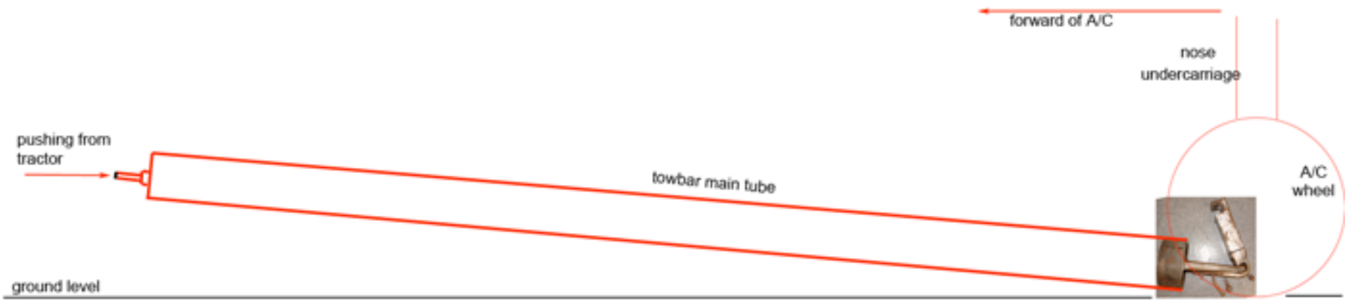


Figure 7-2 : Final resting position of towbar

It is first noted that the examination of the microstructure revealed no problem with materials at the weld areas. That is, the materials were not adversely affected.

In arriving at the final shape of the towbar head as shown Figure 7-2, it is likely that the following sequence of event occurred:

a. The large shear bolt was shear fractured.
b. Due to the weight distribution of the towbar and the loss of the large shear bolt, an eccentricity, say 10 mm, was set up, leading to bending stress on the plates due to the applied pushing force from the tractor.
c. The top plate bent. When bending increased, the bolt of about 16 mm in diameter was sheared. The bending action continued very fast with the plates going down toward the ground. That is, the main tube rotated.
d. The top plate broke off when it reached the maximum stress bearable at the root of the plate. Bending continued with the bottom plate, until it was folded into the shape as shown in Figure 7-1.

The second moment of area, I, of the top or bottom plate is = $(101)(13)^3/12 = 18491\ mm^4$. Assuming that bending is initially dominant at one of the plate, i.e. the top plate, and that if there is a 10 mm eccentricity, then there exist a moment on this plate. Using Engineer's Theory of bending, the bending stress = (P)(10)(6.5)/18491. If the bending stress is greater than the yield stress, then permanent deformation will occur. In Table 2, the yield stress of the plate material was found to be 293 MPa. Using this information, P is found to be 83,351 N. When this force was attained, the top plated was bent, causing the gradual bending of the bottom plate at the same time. As the top plate deformed, it moved relatively to the plate of the head-to-tube connector. Although the hole in the plate of the head-to-tube connector was nearly double that of the bolt, the large shear deformation cause shearing of the bolt of about 16 mm in diameter. Subsequently the deformation happened even faster. The results in Table 6-1 show that the ultimate tensile stress (UTS) of the bolt material is 954 MPa. The ultimate shear stress can be estimated by multiplying 0.4 to the UTS. So the ultimate shear stress is 382 MPa. As the area of the bolt is known, the minimum force required to shear fracture this bolt is 74,420 N. This was seen to be possible as P was larger than this value initially to cause the bending of the top plate.

When the value of P > 83,351 N, the large shear bolt would have failed first. This is the main reason for the set up of the eccentricity, due to the weight of various parts in the towbar.

When the pushback action occurs at constant speed, the force acting in the towbar is small. Although the total weight of the A321 aircraft during pushback can be about 90,000 kg, the tractor only needs to overcome the friction in the wheel bearings and the tyres of the aircraft to commence pushback. The force required will be much less than 83,351 N. So this action will not cause bending of the top plate.

Assuming that there is a sudden deceleration in the aircraft, then the towbar will see a force from the tractor. As mentioned above, if the force is larger than 83,351 N, the middle bolt will be sheared. It is known that the mass of the tractor is 27,273 kg (60,000 lbs), and so the deceleration required is $83351/27273 = 3.1\ m/s^2$. If the aircraft is being pushed back with an approximate speed of 0.67 m/s (1.5 mph), and the aircraft is brought to rest in 0.2 s, the deceleration will be 3.3 m/s^2. So the breaking of the towbar head assembly is possible if sudden deceleration occurred.

It is very unlikely to be able to apply the excessive force by suddenly increasing the power from the tractor. However, it is possible to provide the loading through the sudden deceleration, e.g. by braking in the aircraft wheels.

8. Conclusions

It was concluded that

a. The welded joint and the surrounding material in the towbar head assembly did not contain observable defects.
b. Sudden deceleration such as aircraft wheel braking provided a sudden force on the towbar. The large shear bolt was most likely shear failed due to this action.
c. The loss of the large shear bolt resulted in eccentricity of the towbar head, resulting in bending of the parallel plates of the towbar head assembly.
d. When the deformation in the top plate became large, the middle bolt of about 16 mm in diameter was sheared to failure.
e. The top plate broke off from the head assembly when the local stress exceeded the ultimate tensile stress. The bottom plate continued to bend to its final shape.
f. When the towbar was brought to rest, the head assembly was nearly on the ground.