



United Arab Emirates



الهيئة العامة للطيران المدني
GENERAL CIVIL AVIATION AUTHORITY

Air Accident Investigation Sector

Serious Incident - Final Report -

AAIS Case No. 08/2011

Failure of Undercarriage AFT Crosstube

Operator: Falcon Aviation Services

Type: Bell 412EP

Registration: A6-FLZ

Location: Zakum West Super Complex (ZWAP)

State of Occurrence: United Arab Emirates

Date of Occurrence: 28 March 2011



الهيئة العامة للطيران المدني
GENERAL CIVIL AVIATION AUTHORITY

OBJECTIVE

This Investigation was performed pursuant to the UAE Federal Act No 20 of 1991, promulgating the Civil Aviation Law, Chapter VII, Aircraft Accidents, Article 48, and in compliance with the UAE Civil Aviation Regulations, Part VI, Chapter 3, and in conformity with Annex 13 to the Convention on International Civil Aviation and in adherence to the Air Accidents and Incidents Investigation Manual.

The sole objective of this Investigation is to prevent aircraft accidents and incidents, by identifying and reducing safety-related risk. The GCAA¹ AAIS² investigations determine and communicate the safety factors related to the transport safety matter being investigated.

All GCAA Investigations Reports are publicly available from:

<http://www.gcaa.gov.ae/en/epublication/pages/investigationreport.aspx>

It is not a function of the GCAA AAIS to apportion blame or determine liability.

¹ The General Civil Aviation Authority (GCAA) is a federal, autonomous body set up to oversee all aviation-related activities in the UAE.

² Air Accident Investigation Sector of the General Civil Aviation Authority (GCAA) is responsible for the investigation of aircraft accidents and incidents, in accordance with Annex 13 to the ICAO Convention. The purpose of the Sector is to enhance aviation safety by determining through Investigation Reports and Safety Studies, Safety Recommendations intended to prevent reoccurrence.



الهيئة العامة للطيران المدني
GENERAL CIVIL AVIATION AUTHORITY

Air Accident Investigation Sector
General Civil Aviation Authority
The United Arab Emirates

Serious Incident Brief

GCAA AAI Report No.:	08/2011
Operator:	Falcon Aviation Services
Aircraft Type and Model:	Bell 412EP
Registration Mark:	A6-FLZ
MSN:	36494
No. and Type of Engines:	Two PT6T-3DF Twin-Pac Turboshaft Assembly
Date and Time (UTC):	28 Marc 2011, 04:02
Location:	Zakum West Super Complex (ZWAP)
Type of Flight:	Non – scheduled air transport
Persons On-board:	13
Injuries:	None
Nature of Damage:	Failed undercarriage aft crosstube

Notes:

- Whenever the following words are mentioned in this Report with first Capital letter, they shall mean the following:

Aircraft- the aircraft involved in this Serious Incident.
Investigation- the investigation into the circumstances of this Serious Incident
Incident- this Serious Incident referred to on the title page of this report
Report- this Serious Incident draft final report
Team- the GCAA AAIS Investigation Team
- Unless otherwise mentioned, all times in this Report are Universal Time Co-ordinated (UTC), (UAE Local Time minus 4 hours).
- Photos used in this Report are taken from different sources and are adjusted from the original for the sole purpose to improve the clarity of the Report. Modifications to images used in this Report are limited to cropping, magnification, file compression, or enhancement of color, brightness, contrast, or addition of text boxes, arrows or lines.



SYNOPSIS

The Aircraft, a Bell 412EP, registration A6-FLZ, operated by Falcon Aviation Services, made an uneventful approach and landing on the helideck of Zakum West Super Complex, about 80 kilometers northwest of Abu Dhabi city.

At approximately 08:02 a.m. local UAE time on 28th March 2011, after the passengers had boarded the aircraft, the commander heard a noise and the aircraft suddenly settled and adopted a nose high attitude. The engines were shut down, the passengers and crew disembarked.

Subsequent examination of the aircraft by the crew showed that the undercarriage aft crosstube had failed, due to metallurgical fatigue. Contributing to this fracture were identified as the following factors:

1. the repeated stress due to cyclic loading on the crosstube,
2. the manufacturing abnormality which created a differential crosstube wall thickness,
3. the metallurgical fatigue, which was not discovered, prior to failure, by the existing inspections,
4. the existing, at the time of the occurrence, inspection intervals,
5. the surface on which helicopters land.

This report is based on data gathered and provided to the Investigation Team during the course of this investigation³.

³ Landing Gear Manufacturer report FA-D412-664-1,
Landing Gear Manufacturer Instructions for Continued Airworthiness ICA-D212-664 Rev 7,
Landing Gear Manufacturer Service Bulletin SB07-1 Rev A,
Landing Gear Manufacturer Service Bulletin SB10-1 Rev A,
Landing Gear Manufacturer Service Bulletin SB11-2 Rev C,
Laboratory 1 Fracture Surface Evaluation G115166 Issue 2,
Laboratory 1 Fracture Surface Evaluation G115167 Issue 1 dated 23 September 2011,
Laboratory 2 Group Quantitative Assessment Project No. 128-11-2894,
Laboratory 2 Group Quantitative Assessment Project No. 128-12-127,
FAA Production Certificate No 100,
FAA TYPE CERTIFICATE DATA SHEET NO. H4SW Revision 27, January 4, 2006,
The Operator's incident report, dated 29 March 2011,
UAE NPA CAAP 71,
UK CAA Safety Regulation Group CAP 437 Standards for Offshore Helicopter Landing Areas, 7th Edition incorporating Amendment 01/2013, dated February 2013,



This factual report supersedes all previous Preliminary and Interim reports concerning this serious incident investigation.

The GCAA lead the investigation and assigned the Investigator in Charge (IIC). Additionally accredited representatives from Canada, as the State of Manufacturer and the USA, as the State of Design, were invited and provided comments to this investigation report. Also, the Operator and the Safety Affairs Sector of the GCAA were invited to provide comments, in accordance with UAE CAR PART VI⁴.

The Report

This report was prepared in accordance with the International Civil Aviation Organization Standards And Recommended Practices, the GCAA CAR Part VI Chapter 3 and has the following format:

1. Factual Information

Provides information that is relevant to understanding the chronology and circumstances of this occurrence. Part 1, Factual Information, has nineteen (19) sub-headings detailing each aspect of the investigation.

2. Analysis

The significance of the relevant facts and circumstances which were presented in the factual information part are discussed, evaluated and analysed in order to determine which events contributed to the serious incident. The purpose of the analysis is to provide a logical link between the factual information and the conclusions that provide the answer to why the accident occurred.

Annex 14 to the Convention on International Civil Aviation Aerodromes volume I Aerodrome Design and Operations, Sixth Edition July 2013,
Annex 14 to the Convention on International Civil Aviation Aerodromes volume II Heliports, Fourth Edition July 2013,
ICAO Doc 9261-AN/903, HELIPORT MANUAL, THIRD EDITION -1995.

⁴ Definitions

Interested Party- Any person, government authority/department, institution, organization, aviation society, air operator, aircraft owner, property owner, ministry or any other body the GCAA finds appropriate to have their limited participation in the investigation or receive comments on the GCAA's draft reports (CAR PART VI page 10, issue 0 dated October 2012).



3. Conclusions

Based on the analysis of the factual information, presents the Findings, the Causal and contributing factors.

- A. Findings are statements of all significant conditions, events or circumstances in the incident sequence. The findings are significant steps in the incident sequence, but they are not always causal or indicate deficiencies.
- B. Causes are actions, omissions, events, conditions, or a combination thereof, which led to this incident.
- C. Contributing factors are actions, omissions, events, conditions, or a combination thereof, which, directly contributed to the incident and if eliminated or avoided, would have reduced the probability of this occurrence, or mitigated the severity of its consequences.

4. Safety Recommendations

Based on the findings of the investigation, recommends safety actions to eliminate or mitigate safety deficiencies, and records the main actions already taken or being taken by the affected entities involved through the process of immediate Prompt Safety Recommendations.

This final report provides the following safety recommendations and Safety Actions taken, intended to prevent the occurrence of a similar event:

Safety Actions already taken

Below is a summary of the safety actions taken by the landing gear manufacturer, the Transport Canada Civil Aviation and the aircraft Operator, because of this occurrence. The Team believes that the safety actions taken mitigate most of the unsafe condition, which caused the landing gear failure.



The Landing Gear Manufacturer

- I. The fatigue analysis that was performed on the D412-664-203 crosstube was revised.
- II. A life limit of 10,000 landings and added an LPI after 7500 landings was established.
- III. This information was released to the customer base via Service Bulletin SB 11-2
- IV. A revision to the ICA followed to include the life limit and the LPI inspection
- V. Coordination was performed so TCCA to issue an Airworthiness Directive
- VI. During the draft final report comments period the Team was informed via the Accredited Representative of Canada⁵ that the landing gear manufacturer following research and development “received a TCCA approval for the improved 412 aft Crosstube which is manufactured from a more fatigue resistant material.”

Transport Canada Civil Aviation

Transport Canada issued an Airworthiness Directive for the crosstube (AD-CF-2012-14R1), which adds a life limit of 10,000 landings to the crosstube and removes from service any crosstubes with more than 10,000 accumulated landings.

Federal Aviation Administration

The USA Federal Aviation Administration issued an Airworthiness Directive for the crosstube (Docket No. FAA-2013-0145; Directorate Identifier 2012-SW-059-AD; Amendment 39-17554; AD 2013-16-16), which adds a life limit of 10,000 landings to the crosstube and removes from service any crosstubes with more than 10,000 accumulated landings.

⁵ Electronic communication dated 23 May 2014.



The Aircraft Operator

Following the two events the Operator proactively imposed a 2500 landings LPI, which was significantly lower than the manufacturer's 7500 landing PLI limit. The 10,000 landings life limits remained.

Safety Recommendations

The investigation report contains two Safety Recommendations made to the GCAA/Aerodromes:

The State of the Operator

SR 22/2014 The GCAA/Aerodromes should ensure that the current regulations accommodate the need for non-slip material on offshore helidecks' surface, where UAE registered helicopters are operating.

SR 23/2014 The GCAA/Aerodromes should ensure that all helidecks, where UAE registered helicopters operate and all offshore helidecks in the UAE, meet the same safety surface standards.



ABBREVIATIONS AND DEFINITIONS

AAIS	The Air Accident Investigation Sector
ADC	Aerodrome Controller
AFM	Airplane Flight Manual
AMM	Aircraft Maintenance Manual
ATPL	Air Transport Pilot License
BHTC	Bell Helicopter Textron Canada
BHTI	Bell Helicopter Textron Incorporated
CAA	Civil Aviation Authority
CAAP	United Arab Emirates, General Civil Aviation Authority's, Civil Aviation Advisory Publication
CAR	Civil Aviation Regulations
CAS	Calibrated Air Speed
CAVOK	Ceiling and Visibility are OK
C.G.	Centre of Gravity
cm	Centimeter
CoA	Certificate of Airworthiness
CoR	Certificate of Registry
CPL	Commercial Pilot License
CVR	Cockpit Voice Recorder
CSN	Cycles Since New
DAS	Dart Aerospace
Doc	Document
DOI-OAS	Department of Interior of the United States- Office of Aircraft Services
EAS	Equivalent Air Speed
ECCN	Export Control Classification Number
ETD	Estimated Time of Departure
E.W.	Empty Weight



FAA	The Federal Aviation Administration of the United States
FAR	The Federal Aviation Regulations
FATO	Final approach and takeoff area
FD	Flaps Down
FDR	Flight Data Recorder
FPI	Fluorescent penetrant inspection
ft	Feet (distance unit)
GCAA	General Civil Aviation Authority of the United Arab Emirates
GD	Gear down
GMC	Ground Movement Controller
GNS	Global Navigation System
GU	Gear Up
Hp	Horsepower (power unit)
hPa	Hectopascal (pressure unit)
hrs	Hours
IAS	Indicated Air Speed
IAW	In accordance with
ICA	Instructions for Continued Airworthiness
ICAO	International Civil Aviation Organization
Investigation	The investigation into this occurrence
IFR	Instrument Flight Rules
kts	Knot(s)
lb	Pound(s) (weight unit)
LG	Landing Gear
LH	Left Hand
LT	Local time of the United Arab Emirates
LPI	Liquid Penetrant Inspection
m	Meter(s)
MAC	Mean Aerodynamic Chord
MCTOW	Maximum Certified Take Off Weight



METAR	A format for reporting <u>weather</u> information
MSN	Manufacturer Serial Number
MLG	Main Landing Gear
NLG	Nose Landing Gear
NM	Nautical Miles (distance unit)
No.	Number
NPA	Notice of proposed amendment
NTSB	The National Transportation Safety Board of the United States
OAT	Outside Air Temperature
PIC	Pilot-in-Command
PPL	Private Pilot License
psi	Pounds per square inch (pressure unit)
QNH	The barometric altimeter setting that will cause the altimeter to read airfield elevation when on the airfield.
QFE	The barometric altimeter setting that will cause an altimeter to read zero when at the reference datum of a particular airfield.
RH	Right Hand
RPM	Revolutions Per Minute
RWY	Runway
s	Second(s)
SEM	Scanning Electron Microscope
SPIFR	Single Pilot Instrument Flight Rules
STC	Supplemental Type Certificate
TAS	True Air Speed
TAWS	Terrain awareness and warning system
TC	Type Certificate
TCCA	Transport Canada Civil Aviation
TTSN	Total Time Since New
TSLO	Time Since Last Overhaul
TSN	Time Since New-flight hours
TWY	Taxiway



الهيئة العامة للطيران المدني
GENERAL CIVIL AVIATION AUTHORITY

UAE	The United Arab Emirates
UK	United Kingdom
UTC	Coordinated Universal Time
VFR	Visual Flight Rules
ZAP	Zakum PLaatform
ZWAP	Zakum West Platform



Contents

OBJECTIVE	1
Serious Incident Brief	2
SYNOPSIS	3
Safety Actions already taken	5
The Landing Gear Manufacturer	6
Transport Canada Civil Aviation	6
Federal Aviation Administration	6
The Aircraft Operator	7
Safety Recommendations	7
The State of the Operator	7
ABBREVIATIONS AND DEFINITIONS	8
List of Tables	14
List of Figures	14
List of Photos	15
List of Images	16
1. FACTUAL INFORMATION	17
1.1 HISTORY OF FLIGHT	17
1.2 INJURIES TO PERSONS	19
1.3 DAMAGE TO AIRCRAFT	20
1.4 OTHER DAMAGE	23
1.5 PERSONNEL INFORMATION	24
1.6 AIRCRAFT INFORMATION	25
1.6.1 Aircraft General Information Type Certificate	25
1.6.2 Bell 412EP General Information	26
1.6.4 The landing gear manufacturer	29
1.7 METEOROLOGICAL INFORMATION	29
1.8 AIDS TO NAVIGATION	30
1.9 COMMUNICATIONS	30
1.10 LANDING AREA INFORMATION	31



1.11	FLIGHT RECORDERS	32
1.12	WRECKAGE AND IMPACT INFORMATION	32
1.13	MEDICAL AND PATHOLOGICAL INFORMATION.....	32
1.14	FIRE	32
1.15	SURVIVAL ASPECTS.....	32
1.16	TESTS AND RESEARCH	33
1.16.1	Test performed in the UAE	33
1.16.2	Tests performed by the landing gear manufacturer.....	46
1.17	ORGANIZATIONAL AND MANAGEMENT INFORMATION	59
1.18	ADDITIONAL INFORMATION	59
1.18.1	Industry Crosstube failures.....	59
1.18.3	A6-FLV Aft Crosstube Failure tests in the UAE.....	61
1.18.4	Previously Reported Bell 412EP Undercarriage Aft Crosstube Failures69	
1.18.7	The Regulatory Framework.....	70
1.18.7.2	UAE GCAA Regulations CAR PART IX	71
1.18.7.4	The UK CAA - CAP 437 Standards for Offshore Helicopter Landing Areas.....	74
1.19	USEFUL OR EFFECTIVE INVESTIGATION TECHNIQUES.....	75
2.	ANALYSIS.....	75
2.1	GENERAL.....	75
2.2	Pilot and maintenance reports for previous flights.....	76
2.3	Analysis of previous undercarriage crosstube failures.	76
2.4	Tests / Examination.....	77
2.5	The fractured crosstube occurrences experienced by the Operator.	78
3.	CONCLUSIONS	81
3.1	GENERAL.....	81
3.2	FINDINGS.....	81
4.	SAFETY RECOMMENDATIONS	83
4.1	FINAL REPORT SAFETY RECOMMENDATIONS.....	83
4.1	Safety Actions Taken	83



4.2 Safety Recommendations 84

List of Tables

Table 1. Injuries to persons.....	19
Table 2. Commander Flying Experience as of 28 March 2011	24
Table 3. First Officer Flying Experience as of 28 March 2011.....	24
Table 4. General information A6-FLZ.....	26
Table 5. Scheduled and performed inspections A6-FLZ.	27
Table 6. Meteorological Information of the occurrence site.....	29
Table 7. Meteorological information Abu Dhabi Bateen Airport, before and after the event.	29
Table 8. Meteorological Information Abu Dhabi International Airport, before and after the event.	30
Table 9. Hardness survey values of the A6-FLZ crosstube.....	42
Table 10. Effect of Friction on Crosstube Stress.....	48
Table 11. Total Load Cycles Based on Measured Striation Spacings	51
Table 12. Summary of all known crosstubes failures	59
Table 13. Total Load Cycles Based on Measured Striation Spacings.....	63
Table 14. Striation spacing in different areas	68

List of Figures

Figure 1. Approximate location of Zakum West Super Complex	17
Figure 2. Zakum Field.	18
Figure 3. Bell 412 location of Crosstube Failure.....	21
Figure 4. Landing Gear Assembly and Attaching Parts.....	28
Figure 5. Approximate position of the Zakum field.....	31
Figure 6. Fracture surface beach marks of crosstube at 20X.	43
Figure 7. Shows the fracture surface having fatigue striations of crosstube examined at 1000X.....	44
Figure 8. Shows grain pattern adjacent to fracture surface of crosstube ~50X	45

Figure 9.	Microstructure of the fractured section examined at 100X.....	46
Figure 10.	The fractured component as received by the testing facility.	49
Figure 11.	Image showing fatigue striations (parallel features) near the crack origin. 52	
Figure 12.	Image showing fatigue striations (parallel features) near the crack origin. 52	
Figure 13.	Image showing fatigue striations (parallel features) at the middle of the fatigue fracture zone.....	53
Figure 14.	Image showing fatigue striations (parallel features) adjacent to the final fracture zone.....	53
Figure 15.	Striations observed at 0.16 mm away from the crack initiation area.	56
Figure 16.	Striations observed at 0.67 mm away from the crack initiation area	57
Figure 17.	Striations observed at 1.79mm away from the crack initiation area.	57
Figure 18.	Striations observed at 2.19 mm away from the crack initiation area.	58
Figure 19.	Variation in striation spacing.	58
Figure 20	Fatigue Cracked Area	67
Figure 21	Variation in Striation spacing.	68

List of Photos

Photo 1	A6-FLZ following the crosstube fracture.	19
Photo 2.	A6-FLZ following aft crosstube failure	20
Photo 3.	Damage to Fuselage Skin Panels fractured crosstube and Aft Crosstube Tunnel Skin Panels.	21
Photo 4.	Damage to Fuselage Skin Panels and Aft Crosstube Tunnel Skin Panels.	22
Photo 5.	Fractured crosstube attached to the helicopter.....	22
Photo 6.	Fracture surface exhibited beach marks / striations originating from the surface of the inner radius of the bend.....	23
Photo 7.	The failed crosstube as received in the metallurgical Laboratory.	33
Photo 8.	Location of the section cut examined for fracture surface and micro examination from A6-FLZ.	37
Photo 9.	Fractured surface exhibiting beach marks originating from the surface of the inner radius of the bend.	38

Photo 10.	Shows the crack initiation point and different regions of fracture.....	39
Photo 11.	A6-FLZ failed crosstube indicating the originating crack along with the thickness difference.	39
Photo 12.	A6-FLZ failed crosstube as received in the metallurgical laboratory.	40
Photo 13.	Shows the cracks found on the A6-FLZ paint stripped crosstube after FPI Inspection.	41
Photo 14.	A6-FLZ paint stripped crosstube hardness survey location identifications.....	42
Photo 15.	The ultrasonic equipment used to measure the failed crosstube.....	47
Photo 16.	The crosstube thickness measurement utilising ultrasonic equipment.	47
Photo 17.	The fatigue portion of the fracture surface is bright with semicircular beach marks.....	50
Photo 18.	Pieces of the broken component and mount as received by the second laboratory. 54	
Photo 19.	The fractured surface.....	55
Photo 20.	Fatigue crack area.....	55
Photo 21.	Fractured surface.....	67

List of Images

Image 1	Showing fatigue striations (parallel features) at the middle of the fatigue fracture zone.....	64
Image 2.	Faint fatigue striations (parallel features) of a field near the crack origin (field 2). 65	
Image 3.	Fatigue striations (parallel features) adjacent to the final fracture zone.	65

1. FACTUAL INFORMATION

1.1 HISTORY OF FLIGHT

On March 28 the flight crew attended a normal briefing in their headquarters in Abu Dhabi Bateen airport and departed for the intended route, which included a stop on Zakum West Super Complex, which is located approximately 80 kilometers northwest of Abu Dhabi city, UAE.



Figure 1. Approximate location of Zakum West Super Complex⁶

Following an uneventful flight, the Aircraft landed on the Zakum West Super Complex helideck. Eleven passenger embarked and the flight crew briefed them for their intended flight to Abu Dhabi and ensured that the passengers' seat belts were fastened and their life jackets were on. The helicopter engine was running at 100% RPM.

⁶ Source : http://www.subseaiq.com/data/Project.aspx?project_id=592 (not to scale detail)



Figure 2. Zakum Field.⁷

While waiting for the platform coordinator to interact with the next landing site, the crew performed the last checks before departure. As the flight crew carried out the pre-takeoff checks, the wind was from the northwest at approximately 20 knots and the outside air temperature was 21 degrees on the Celsius scale. The aircraft weight was 11,580 Lbs. Just before the helicopter's lift off the crew heard a loud noise. At the same time the aircraft adopted a nose high attitude inclined slightly to the right.

The crew shut down the engine, and briefed the passengers. As soon as the blades came to a complete stop, the commander exited the aircraft in order to assess the situation. He quickly determined that it was safe to disembark the passengers. Following passengers disembarkation, the flight crew inspected the lower aft fuselage of the helicopter and they noted that the undercarriage aft crosstube has sheared. The aircraft came to rest on the right hand side (RHS) aft jacking point.

⁷ Source : http://www.subseaiq.com/data/Project.aspx?project_id=592



Photo 1 A6-FLZ following the crosstube fracture.

1.2 INJURIES TO PERSONS

There were no injuries to the passengers or crew.

Injuries to persons						
Injuries	Flight Crew	Cabin Crew	Other Persons Onboard	Passengers	Total Onboard	Others
Fatal	0	0	0	0	0	0
Serious	0	0	0	0	0	0
Minor	0	0	0	0	0	0
None	2	0	11	0	13	0
TOTAL	2	0	11	0	13	0

Table 1. Injuries to persons

1.3 DAMAGE TO AIRCRAFT



Photo 2. A6-FLZ following aft crosstube failure

Damage to the Aircraft consisted of the failed undercarriage right side of the aft crosstube, part number D412-664-203, and resulting damaged fuselage skin panels in the area of the aft crosstube tunnel, near the grounding receptacle, on both sides of the fuselage.

The rocking beam pivot assembly was intact and crosstube saddles remained intact. It was clear that damage to the airframe was restricted to the right side outboard of the right hand aft crosstube airframe fitting. The damage was confined to the skin panel only and did not affect the primary structure. Damage to the left hand side had been prevented by the fractured crosstube coming into contact with the helideck surface. However it was evident that the forward crosstube had been stretched in a manner that rendered it unserviceable for flight.

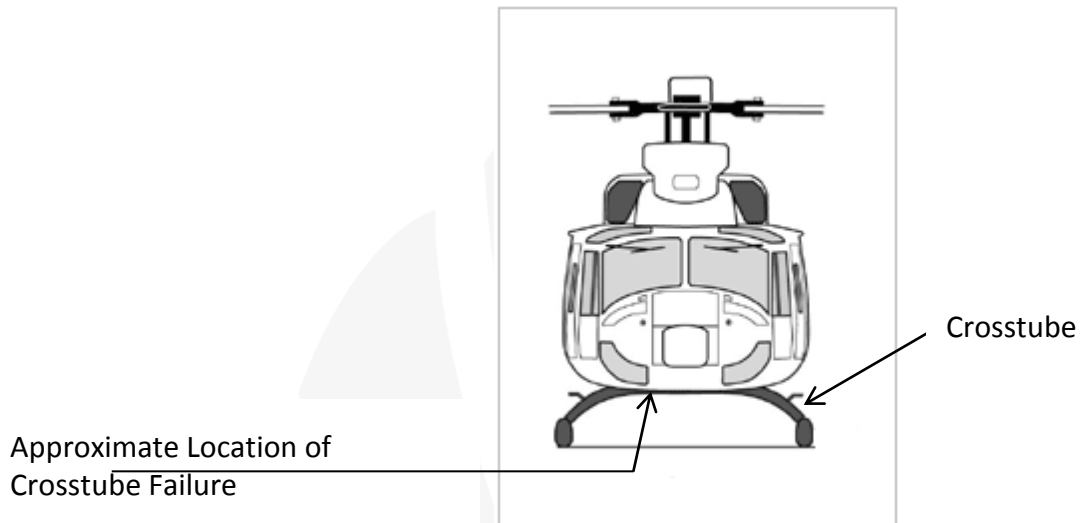


Figure 3. Bell 412 location of Crosstube Failure

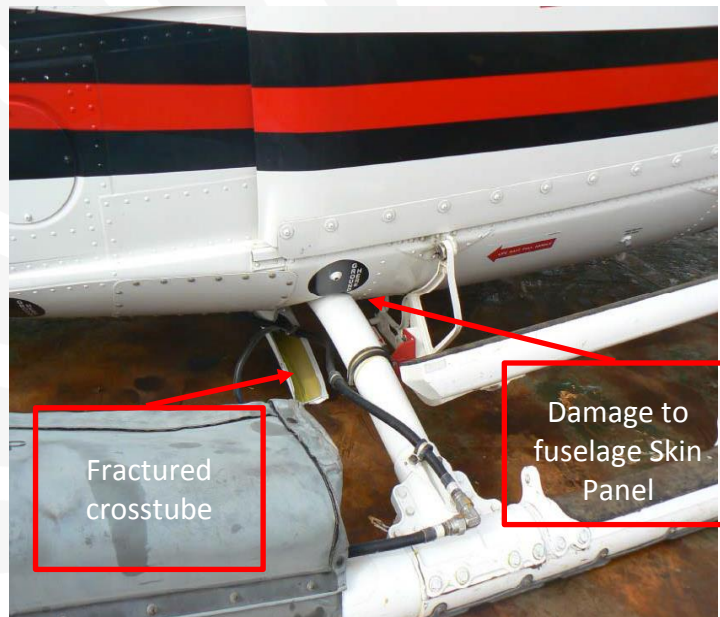


Photo 3. Damage to Fuselage Skin Panels fractured crosstube and Aft Crosstube Tunnel Skin Panels.



Photo 4. Damage to Fuselage Skin Panels and Aft Crosstube Tunnel Skin Panels.



Photo 5. Fractured crosstube attached to the helicopter.

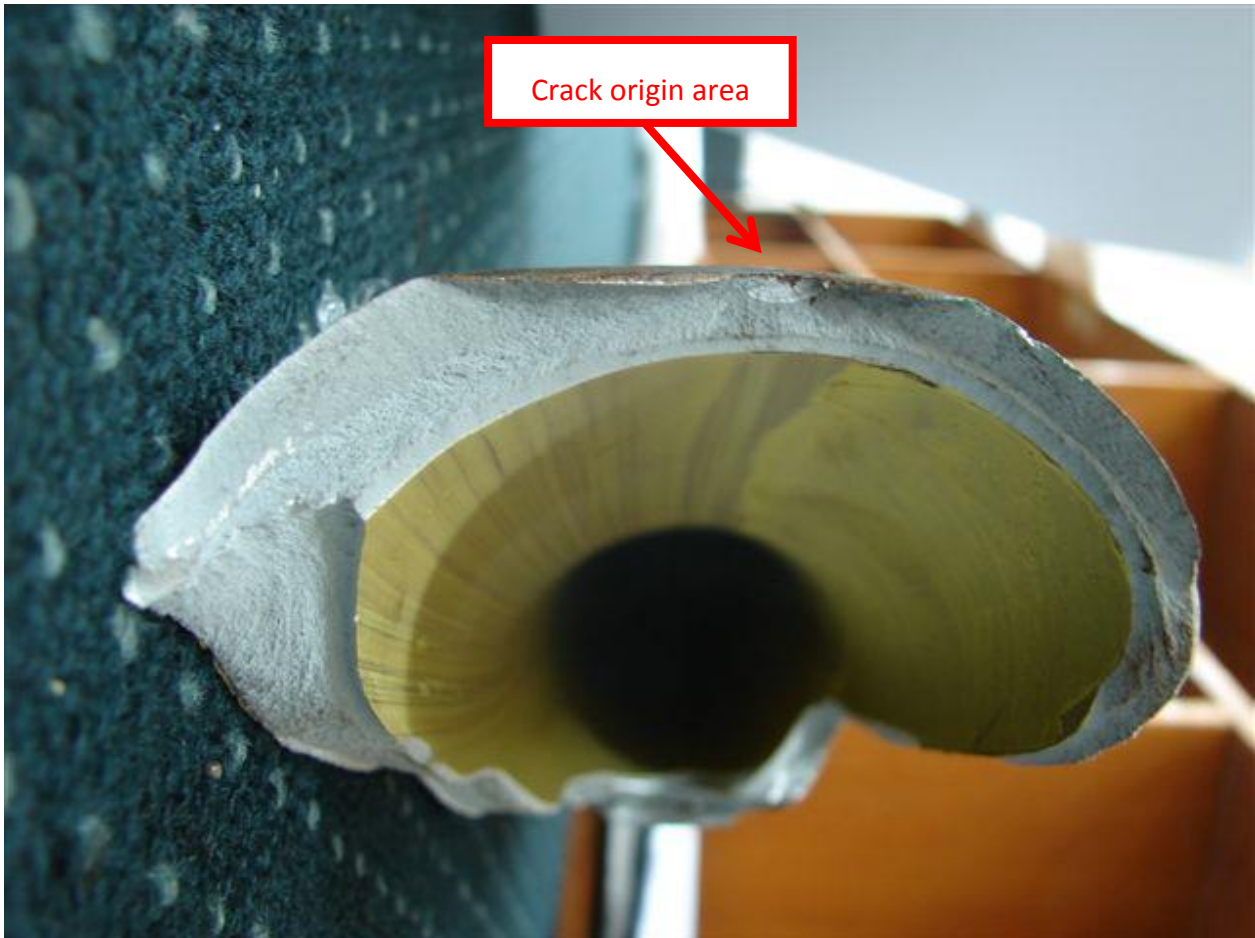


Photo 6. Fracture surface exhibited beach marks / striations originating from the surface of the inner radius of the bend.

The crew reported that flights prior to the incident flight had been normal and there had been no hard landing on any flight. In addition, there was no hard landing recorded in the aircraft technical log.

1.4 OTHER DAMAGE

There was no other damage.



1.5 PERSONNEL INFORMATION

The Commander:

Date of birth	28 July 1976
Class & Validity of medical	Class: 1 Valid until 16 August 2011
Total all flying hours	3600
Total flying hours on B412	1750
Total last 28 days	73
Line & Proficiency check	Line Check valid till - 31 October 11 Proficiency Check valid till (OPC)– 30 November 11
English Language Proficiency	Level 4

Table 2. Commander Flying Experience as of 28 March 2011

The First Officer:

Date of birth	31 January 1978
Class & Validity of medical	Class: 1 Valid until 28 August 2011
Total all flying hours	4300
Total flying hours on B412	2250
Total last 28 days	75
Line & Proficiency check	Line Check valid till - 31 December 11 Proficiency Check valid till (OPC)– 30 May 11
English Language Proficiency	Level 6

Table 3. First Officer Flying Experience as of 28 March 2011.



1.6 AIRCRAFT INFORMATION

1.6.1 Aircraft General Information Type Certificate

Bell Helicopter is an American rotorcraft manufacturer headquartered in Hurst, Texas, near Fort Worth. The Bell commercial rotorcraft products are manufactured in Mirabel, Quebec, Canada. The Type Certificate Details⁸ are the following:

Type Certificate:	H4SW
Issued by :	Federal Aviation Administration
Manufacturer:	Bell Helicopter Textron (212 s/n 35001 and 412 s/n 36001 on)
Model(s) :	212, 412, 412EP
Engine :	PT6T-3, -3B Twin Power Section (Model 212) PT6T-3B, -3BE, -3D, -3BF or -3BG (Model 412) PT6T-3D, -3DE or -3DF (Model 412EP)
MCTOW :	11,200 lb. (212) 11,600 lb. (412 s/n 33001 thru 33107) 11,900 lb. (412/412EP s/n 33108 thru 33213, and 36001 and on)
Noise Standard:	Not Applicable (212) FAR 36, Subpart H dated Feb 5, 1988, Amend 36-14 (412/412EP)

In accordance with the FAA Production Certificate⁹ to Bell Helicopter Textron, INC. amended September 29, 2011, the Type Certificate of the 412EP is H4SW¹⁰, as per the License Agreement between Bell Helicopter Textron Incorporated (BHTI) and Bell Helicopter Textron Canada (BHTC) dated December 2, 1996.

⁸ FAA TCDS No H4SW, revision 27 dated January 4, 2006.

⁹ FAA Production Certificate No 100 dated July 2, 1960.

¹⁰ FAA Production Certificate No 100 dated July 2, 1960, page 3 of 4 [FAA FORM 8120-3 (7-67)] Initial production date authorized July 5, 1995



1.6.2 Bell 412EP General Information

The Bell 412EP is a medium sized, twin turbine powered, helicopter, powered by the Pratt and Whitney PT6T-3DF Twin-Pac gas turbine engine, a crew of two pilots and can carry 13 passengers. It has a maximum speed of 140Kts and a range of 290nm (see below table).

Make and model (as shown in the CoA)	Bell 412EP
MSN	36494
Max. TO/LDG Mass	11,900lbs / 11,900lbs
Last C of A inspection	28 October 2010
C of A Category	Transport (Passenger)
Aircraft Station License	#0019467/09 Issued 06 September 2010
Insurance Validity Period	Exp 14 October 2012
Last CMR Date / Next Due CMR	14 February 2011 / 14 June 2011
TTSN	1839.25Hours
Total Landings	11315
Crosstube assembly P/N	D412-664-203
Crosstube assembly Serial number	LT-09-004674

Table 4. General information A6-FLZ.



Visual Inspection	Daily interval	IAW BHT 412 MM Chapter 5.5
Visual Inspection	Weekly interval	IAW BHT 412 MM Chapter 5.9
Detailed visual with X 10 Mag glass (skid Caps removed Landing gear installed)	Each 300 hour interval	IAW BHT B412MM Chapter 5.10 in conjunction with Dart ICA D212-664 Including deflection check
Detailed Visual Inspection with Landing Gear Removed	Each 2 years interval	IAW Dart ICA D212-664
Last Daily inspection accomplished	27 March 2011 at 1837.55	
Last Weekly inspection accomplished	26 March 2011 at 1831.55 W/P11177	
Last 300 Hour inspection accomplished	20 March 2011 at 1805.00 W/P 11117	
2 year inspection	Not due until October 2011	

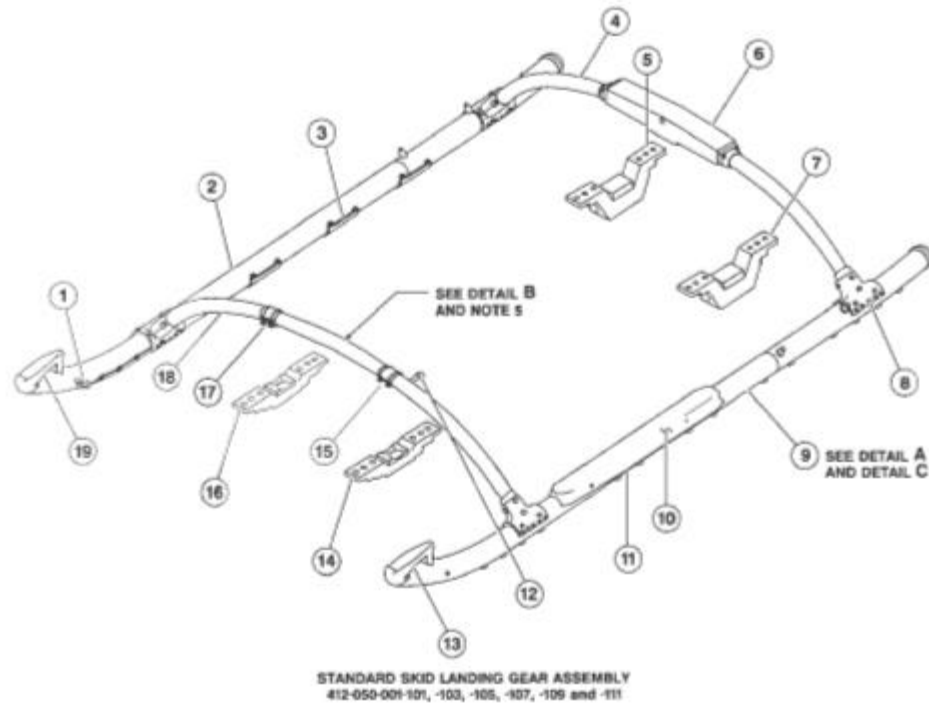
Table 5. Scheduled and performed inspections A6-FLZ.

The aircraft was manufactured in Canada and all of the operator's Bell 412EP helicopters are equipped with a High Crosstube Undercarriage which is required to enable the installation of a skid mounted Emergency Floatation System with automatically deployable life raft. This installation is approved by Transport Canada (Supplemental Type Certificate (STC) SH01-9), EASA (STC IM.R.S.01304) and the FAA (STC SR01298NY).

The same Operator experienced another crosstube failure (D412-664-203), on another Bell 412, registration A6-FLV, 12 days before the A6-FLZ crosstube failure (investigated in this report). The A6-FLV event is also under investigation by the GCAA.

1.6.3 The Bell 412 landing gear

The figure below provides an overview of the standard skid landing gear assembly of the Bell 412¹¹ (see figure 4).



- | | |
|-------------------------------|--|
| 1. Tow ring | 11. Skid shoe |
| 2. Skid tube | 12. Passenger step electrical connector |
| 3. Skid shoe | 13. Step |
| 4. Crosstube | 14. Landing gear cap fitting |
| 5. Landing gear cap fitting | 15. Landing gear bearing and retaining support |
| 6. Aft crosstube support beam | 16. Landing gear cap fitting |
| 7. Landing gear cap fitting | 17. Landing gear bearing and retaining support |
| 8. Saddle | 18. Crosstube |
| 9. Skid tube | 19. Step |
| 10. Passenger step | |

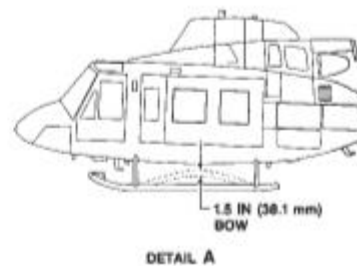


Figure 4. Landing Gear Assembly and Attaching Parts.

¹¹ Bell Helicopter Textron 412 Maintenance Manual, (BHT-412-MM-5), ECCN EAR99, 32-00-00 page 11, dated 29 October 2009 revision 13.

1.6.4 The landing gear manufacturer

The figures below show the helicopter landing gear's aft crosstube design in more detail (see figures 5 & 6).

1.7 METEOROLOGICAL INFORMATION

Table 6 shows the METAR Report at the time of the Incident.

METAR Report	
Wind:	320°/20kts
Weather	CAVOK
OAT	21 °C

Table 6. Meteorological Information of the occurrence site

There were no significant adverse meteorological conditions in the area at the time of the Incident.

The following were the METARs and TAF from Abu Dhabi Bateen Airport, which was the initial departure airport and the closest to the occurrence site before and after the event:

SA	28/03/2011 07:00->	METAR OMAD 280700Z 30012KT 270V330 CAVOK 24/13 Q1017 A3005=
SA	28/03/2011 06:00->	METAR OMAD 280600Z 30012KT CAVOK 23/13 Q1017 A3005=
SA	28/03/2011 05:00->	METAR OMAD 280500Z 30011KT CAVOK 22/14 Q1017 A3005=
SA	28/03/2011 04:00->	METAR OMAD 280400Z 30010KT CAVOK 21/14 Q1017 A3003=
SA	28/03/2011 03:00->	METAR OMAD 280300Z 30006KT CAVOK 20/1 Q1016 A3001=
FT	28/03/2011 05:00->	TAF OMAD 280500Z 2806/2912 31012KT 9000 NSC PROB30 2810/2812 31017KT 4900 BLDU=

Table 7. Meteorological information Abu Dhabi Bateen Airport, before and after the event.

Following were the METARs and TAF from Abu Dhabi International Airport, which is close to the occurrence site before and after the event:

SA	28/03/2011 07:00->	METAR OMAA 280700Z 30012KT CAVOK 24/13 Q1017 A3003 NOSIG=
SA	28/03/2011 06:00->	METAR OMAA 280600Z 31011KT CAVOK 23/14 Q1017 A3004 NOSIG=
SA	28/03/2011 05:00->	METAR OMAA 280500Z 29011KT CAVOK 22/14 Q1017 A3004 NOSIG=
SA	28/03/2011 04:00->	METAR OMAA 280400Z 30008KT CAVOK 21/15 Q1016 A3002 NOSIG=
SA	28/03/2011 03:30->	METAR OMAA NIL=
SA	28/03/2011 03:00->	METAR OMAA 280300Z 29006KT 9000 NSC 20/15 Q1016 A3000 NOSIG=
FT	28/03/2011 05:00->	TAF OMAA 280500Z 2806/2912 30012KT 9000 NSC PROB30 2810/2812 32017KT 4900 BLDU=

Table 8. Meteorological Information Abu Dhabi International Airport, before and after the event.

1.8 AIDS TO NAVIGATION

No navigational aids were used during the time of the occurrence.

1.9 COMMUNICATIONS

Communications with the appropriate Air Traffic Control units were normal, without any reported problems.

1.10 LANDING AREA INFORMATION

The Upper Zakum field is situated about 50 miles (80 kilometers) northwest of Abu Dhabi, the oil field spans more than 288,000 acres (450 square miles) in the waters of the Arabian Gulf.



Figure 5. Approximate position of the Zakum field¹²

As per the evidence submitted by the Operator's investigation report, the landing surface (steel) was considered to be in very poor condition, with no effective non-slip surface application. The actual landing area was very shiny and the deck friction between the helicopter and steel deck was minimal.

¹² Source : http://www.subseaiq.com/data/Project.aspx?project_id=592



1.11 FLIGHT RECORDERS

The aircraft was equipped with recorders as per the GCAA regulations. Flight data was not recovered.

1.12 WRECKAGE AND IMPACT INFORMATION

The aircraft was intact with the exception of the fractured undercarriage aft crosstube and fuselage skin panel damage. The helideck sustained no damage as a result of the Incident.

1.13 MEDICAL AND PATHOLOGICAL INFORMATION

The toxicology testing performed on the collected samples from the PIC did not reveal alcohol or other psychoactive substances that might have affected his performance. No other medical or pathological related information was provided to the Investigation Team.

1.14 FIRE

There was no evidence of fire in flight or after the crosstube fracture.

1.15 SURVIVAL ASPECTS

There was no failure of seats or seat belts following the crosstube fracture, all persons onboard vacated the helicopter without any difficulty.

1.16 TESTS AND RESEARCH

1.16.1 Test performed in the UAE

The failed crosstube was tested at a laboratory in the UAE, in November 2011¹³, in order to determine the possible cause(s) of failure of the landing gear crosstube.

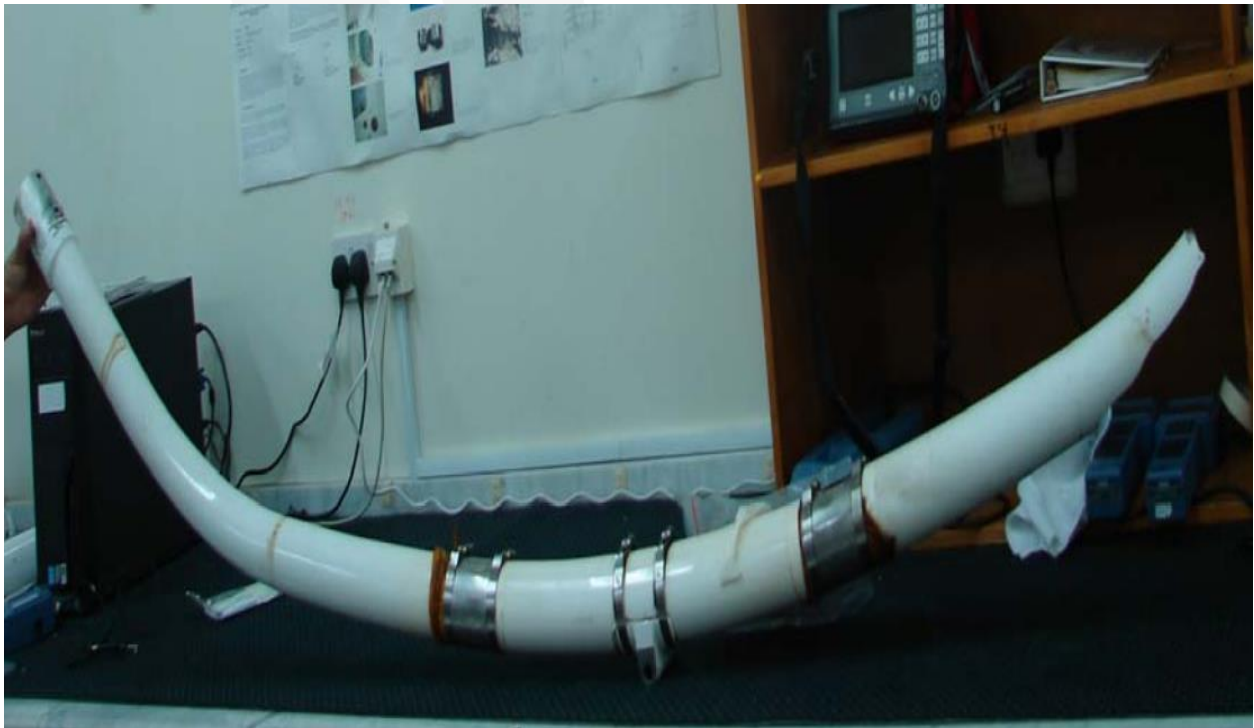


Photo 7. The failed crosstube as received in the metallurgical Laboratory.

¹³ Failure analysis report, Metallurgical laboratory report ADAT/TS/8019 issue 04 M/L/R/ No F-1239 dated 12 May 2011, W/O: AUH 1844715-20.



As per the metallurgical report, the laboratory performed the following examinations:

1. Material Identification

Material identification of the Crosstube was carried out using a Niton Analyzer (THERMO NITON ANALYZER Model: XL3t) to confirm the crosstube material identification.

2. Visual Examination

The tube surface and the fracture surfaces of the cracks were visually examined under different magnifications¹⁴ up to 50X using an OLYMPUS binocular¹⁵ (Model: SZ-PT) for any surface damage such as impact, scoring, deep scratches, corrosion pitting etc. Visual examination of a section on the fractured tube was also carried out after paint stripping.

3. Eddy Current Inspection¹⁶

¹⁴ Magnification is the degree to which the object is enlarged. With a 7x35 binocular, the object will appear to be seven times closer than without the aid of a binocular. The number immediately following the "x" is the diameter in millimeters of the objective (front) lens. The larger the front lenses the more light that is allowed to enter the binocular. A 10x50 binocular has 10 times magnification with a 50mm objective lens. (<http://www.binoculars.com/binocularsfaqarticle.cfm>)

¹⁵ Binocular is a pair of identical or mirror-symmetrical telescopes mounted side-by-side and aligned to point accurately in the same direction, allowing the viewer to use both eyes when viewing objects. (<http://topdefinitions.com/2013/07/30/binoculars-is/>, <http://www.olympusmicro.com/index.html>)

¹⁶ Eddy current is suitable inspection method for the detection of cracks, pits, inclusions and voids on heat exchangers condenser, bearings, spindles, tubing and other metallic conductive surfaces both ferrous and non ferrous in nature. Eddy current can reduce rotating equipment down time by being used as a preventative maintenance tool. (<http://ndteddycurrent.com/>)

Eddy-current inspection, also known as ET inspection in the non-destructive testing industry, is the process of introducing electromagnetic induction to detect flaws on or very close to the surface of a material, component, or similar conductive metal. While eddy current inspection does have several limitations and is not widely used in the industry, it does present interesting options to testing surfaces when compared to dye penetrant and magnetic particle inspection methods. Both magnetic particle and dye penetrant require that the surface of the material be cleaned thoroughly, while eddy current is able to detect surface cracks and irregularities more precisely regardless of how clean the surface



The eddy current inspection was carried out using ELOTEST M2 equipment at a frequency of 2MH along the inner bend radius of tube. Eddy current inspection was carried out both with paint on and also after paint was stripped off.

4. Fluorescent Penetrant Inspection (FPI)¹⁷

Paint stripping by chemical process (using paint stripper Ardrox 2302 for 1 hour duration by immersion technique) was carried out on one of the fractured crosstube to aid examination and confirm the presence of cracks on inner radius of the bend. Further, FPI Inspection was carried out using Magnaflux Penetrant (Zyglo ZL-60C) and Developer (Zyglo ZP-9F) on the paint stripped crosstube and examined under UV light to confirm the cracks.

5. Hardness survey¹⁸

material is. Eddy current also has the advantage of being able to inspect oddly shaped dimensions and cares little about the geometry of the object it's analyzing.

The typical eddy current testing equipment is comprised of a conductive circular coil, which is then placed within a certain proximity of the material. The coil then produces dynamic magnetic fields which penetrate the surface and subsurface of the material, which in turn produces an "eddy current." By using a second coil tuned to listen for differences in the source magnetic field, and the resulting differences in magnetic phase and magnitude, an average impression of the material can then be made. The end result is a quick and reasonably accurate image of the internal surface and characteristics of the target material. The testing equipment used for eddy current inspection is highly portable, and doesn't require any surface preparation or direct contact with the surface material, which is also another benefit. (<http://ndtknowledge.com/eddy-current-inspection/>)

¹⁷ FLUORESCENT PENETRANT INSPECTION (FPI) is a nondestructive testing method for detecting discontinuities (cracks, seams, laps, cold shuts, laminations, and porosity) that are open to the surface. (http://www.saranindustries.com/fluorescent_penetrant.html)

¹⁸ The Metals Handbook defines hardness as "Resistance of metal to plastic deformation, usually by indentation. However, the term may also refer to stiffness or temper, or to resistance to scratching, abrasion, or cutting. It is the property of a metal, which gives it the ability to resist being permanently, deformed (bent, broken, or have its shape changed), when a load is applied. The greater the hardness of the metal, the greater resistance it has to deformation. (http://www.calce.umd.edu/TSFA/Hardness_ad_.htm , <http://www.earlyaviators.com/eboyer.htm>)



- i. Hardness survey was carried out using Krautkramer Branson Portable Hardness Tester (Model: Microdur II) on inner radius and outer radius of the bend to determine hardness variation between these areas. Hardness survey was carried out after paint stripping of the crosstubes.
- ii. Micro¹⁹ Examination

- a. Microscopic Examination²⁰

The section cut from the fracture surface with fatigue striations was also examined under Olympus Metallurgical Microscope (Model: BH-II). The beach marks and striations were examined under 1000X magnification to measure, where possible, the spacing between the striations.

- b. Microstructure Examination²¹

A small section was cut approximately 25mm away from the fracture initiation surface of the crosstube and micro polished, etched with etchant mixture of concentrated HNO₃ 10%, HF 2%, distilled water 88%. The specimen was examined under Olympus Metallurgical Microscope (Model: BH-II) at different magnifications for any metallurgical defects or any abnormalities at as polished and etched conditionn (see below photo).

The metallurgical laboratory report, mentioned in footnote 12, contained the following:

- I. Material Identification

The material analysis performed indicated that the failed crosstube was identified to be manufactured from standard composition of Aluminium Alloy 7075.

¹⁹ **Micro** is a word that comes from the Greek μικρός (*mikrós*), meaning "small".

²⁰ **Microscopy** is the technical field of using microscopes to view objects too small to be seen by the unaided eye but large enough to be studied under a microscope. (<http://www.yourdictionary.com/microscopic>)

²¹ **Microstructure** A microstructure is the way a material comes together on a very small scale. An object's microstructure is not visible by the naked eye, although the patterns present at the microscopic level may replicate at a larger level (<http://www.wisegeek.com/what-is-a-microstructure.htm>). Typically, units of microscopic size about 1 to 100 /im in diameter, which occur in materials. (Science Dictionary: <http://thesciencedictionary.org/microstructure/>)

II. Visual Examination

No external damages, scorings marks or impact were noticed on the crosstube surface. The fractured surfaces of the crosstube exhibited beach marks/ striations originating from the inner radius surface of the bend as shown in photo 8. As it is evident the photo below clearly indicates that there was no external damage close to the originating crack area on the paint surface of the tube.

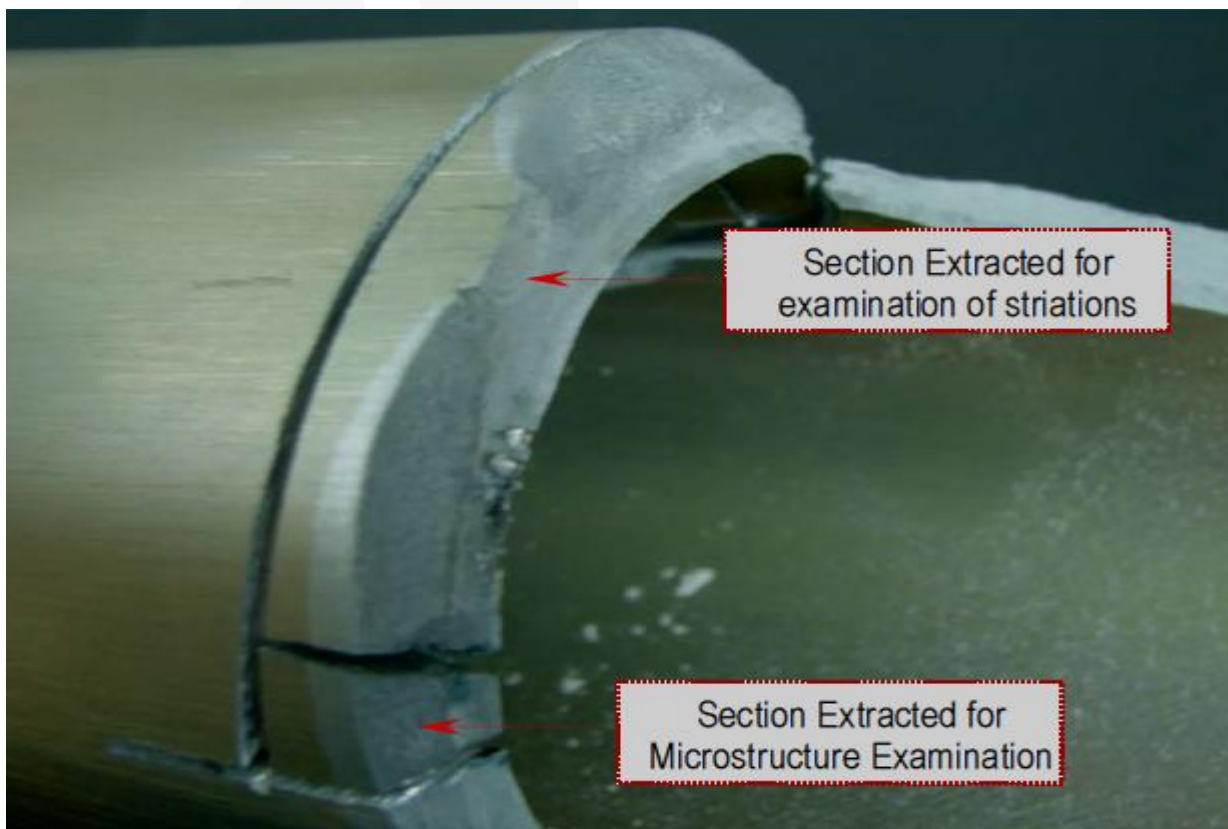


Photo 8. Location of the section cut examined for fracture surface and micro examination from A6-FLZ.

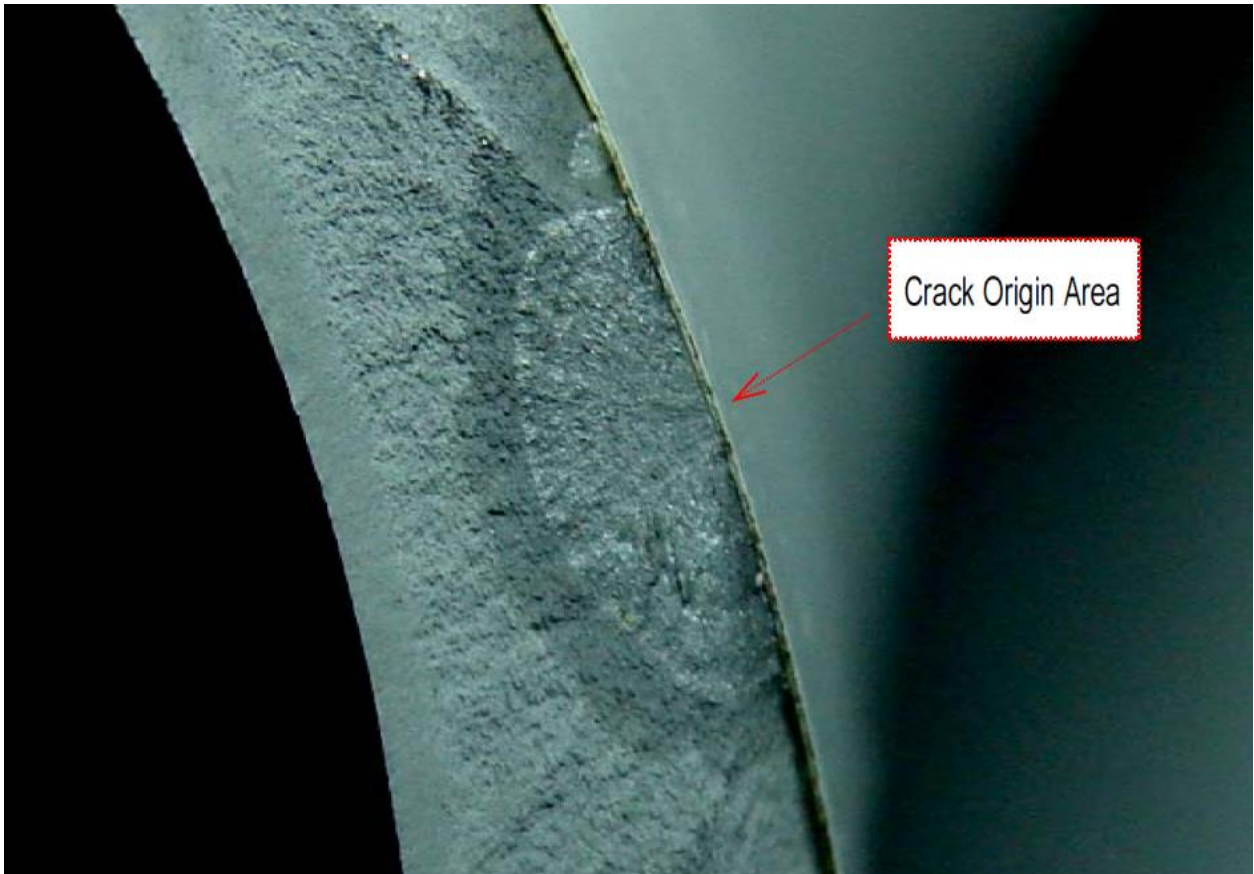


Photo 9. Fractured surface exhibiting beach marks originating from the surface of the inner radius of the bend.

The report indicates that the crack, originated *from inner radius surface of the bend and propagated into the wall thickness for approximately 3.5mm in fatigue mode (which is approximately 45% of tube wall thickness)*. Further, *this thumbnail region the crack propagated in fast overload failure mode*. In the photo below, arrows show the crack propagation path of during fracture. Additionally the large thickness variation of the tube on the section from left to right can be seen (see photo 10).

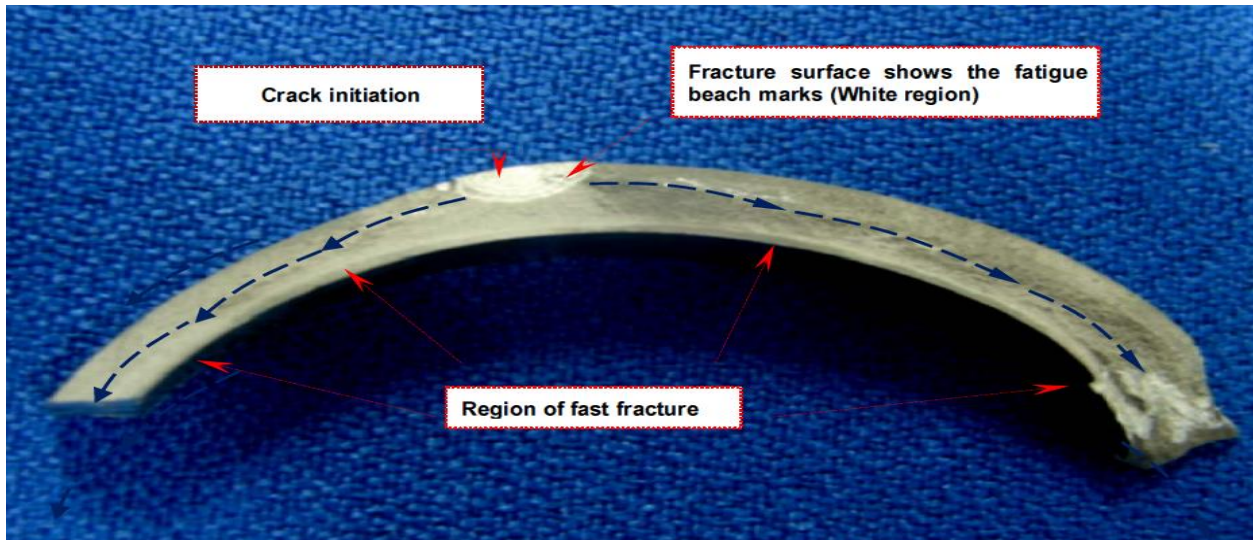


Photo 10. Shows the crack initiation point and different regions of fracture.

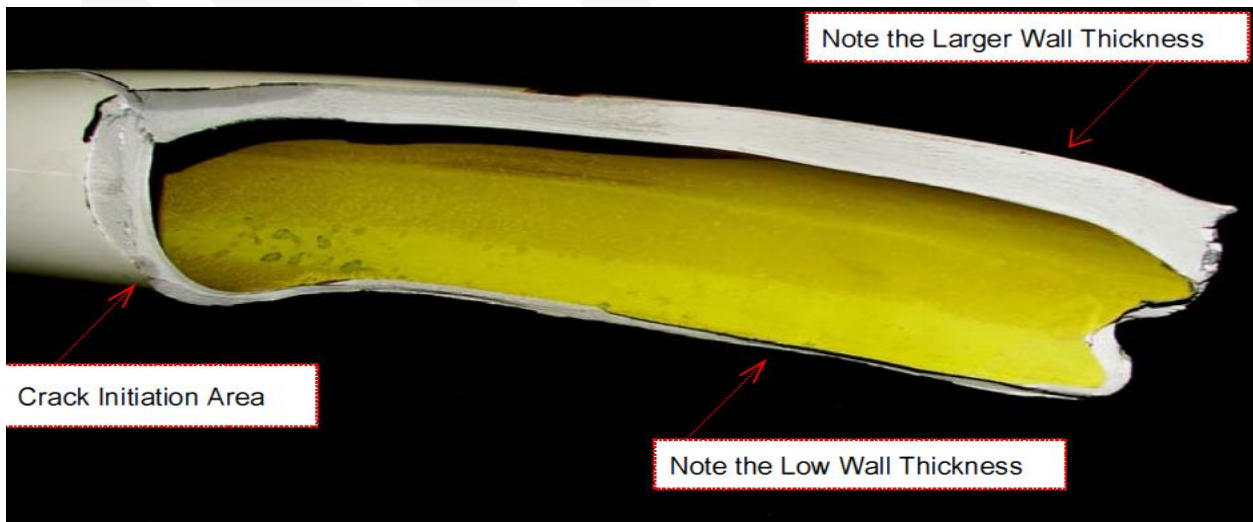


Photo 11. A6-FLZ failed crosstube indicating the originating crack along with the thickness difference.

The laboratory report also indicated *that there were four line indications, suspected to be cracks were visible on the inner radius surface of the crosstube*. In the photo below (photo 12) the red circle indicates the area of the suspected cracks.



Photo 12. A6-FLZ failed crosstube as received in the metallurgical laboratory.

The laboratory measured the suspected cracks, which were found to vary *between 3.4mm to 4.6mm in length along with approximately 4.2mm intervals. These were at a distance of 200mm from the fracture and these indications lie on the inner bend radius of the Tube, from where the fatigue crack originated leading to tube failure.*

III. Eddy Current Inspection

The Eddy Current Inspection confirmed that the four indications were cracks as can be seen in photo 13. The suspected four cracks visible on the surface before the paint strip are shown in the red dotted ellipse.

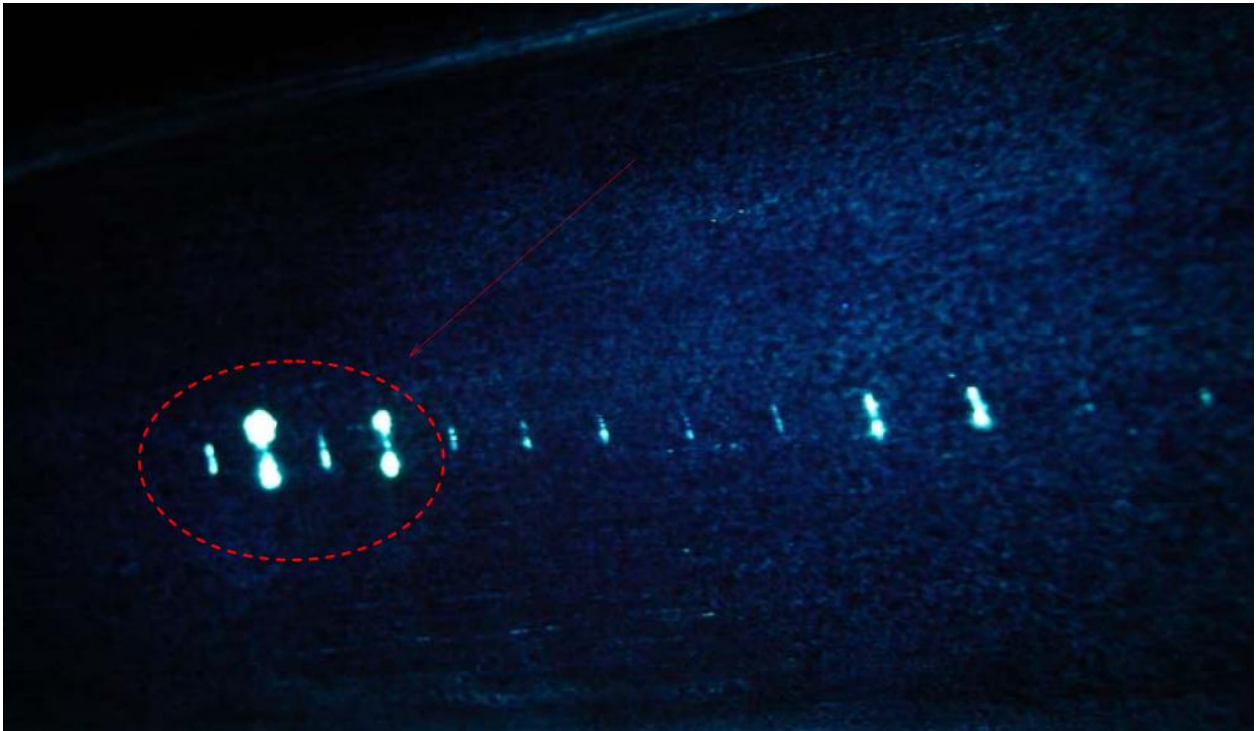


Photo 13. Shows the cracks found on the A6-FLZ paint stripped crosstube after FPI Inspection.

IV. Fluorescent Penetrant Inspection

Following the Fluorescent Penetrant Inspection of the failed section with cracks, it was revealed that there were more cracks as can be seen on photo 13 above, which are close to the already suspected cracks. The cracks that were only revealed with the FPI were adjacent to the four indications stated earlier (see photo 13 above).

V. Hardness Survey

The Hardness survey revealed values ranging between 89-91 HRB. This hardness value confirms the material to be Aluminium Alloy 7075 T6. In addition, the hardness values observed were uniform across the inner and outer radius of the crosstube bend areas (see Table 10 for the results). The results in table 10 have to be read in association with photo 14 below, where the hardness survey location identifications are shown.

S.No	Hardness Test Location Identification	Hardness in HRB (Average of 5 Readings)
1	A1	90
4	B1	90
7	C1	91
1	D1	90
4	A2	89
7	B2	91
1	C2	89
4	D2	90

Table 9. Hardness survey values of the A6-FLZ crosstube.

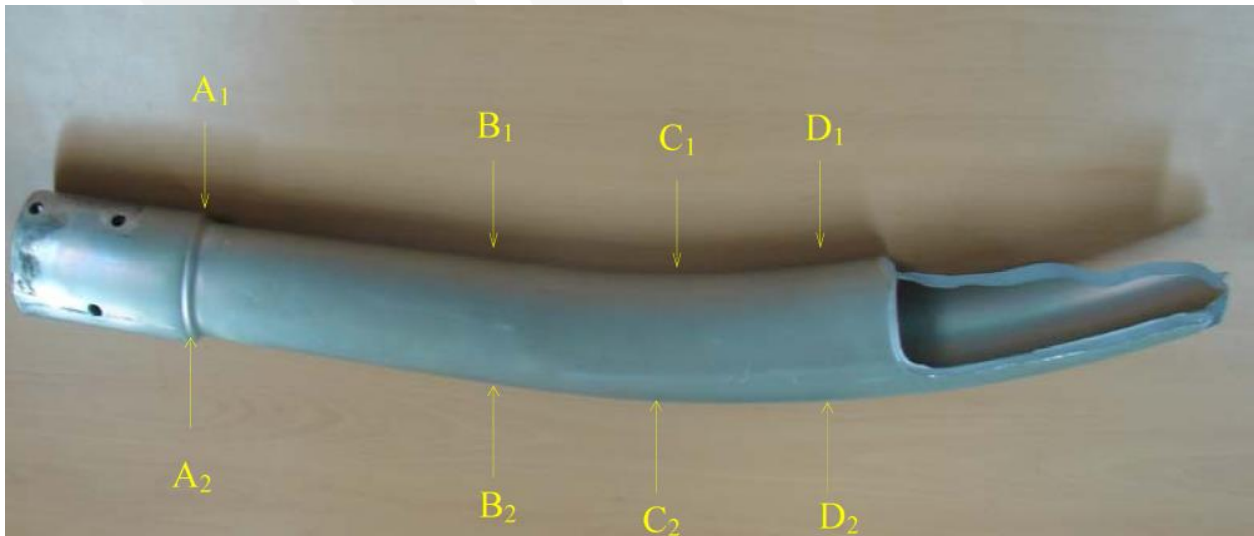


Photo 14. A6-FLZ paint stripped crosstube hardness survey location identifications

VI. Microstructure Examination

a. Microscopic Examination

Fracture surface at the thumb nail region showed seven distinct beach marks with spacing of approximately 0.45mm between them, which can be seen in the figure below. In addition the distance between the two beach marks intervals can be seen (see figure 8).

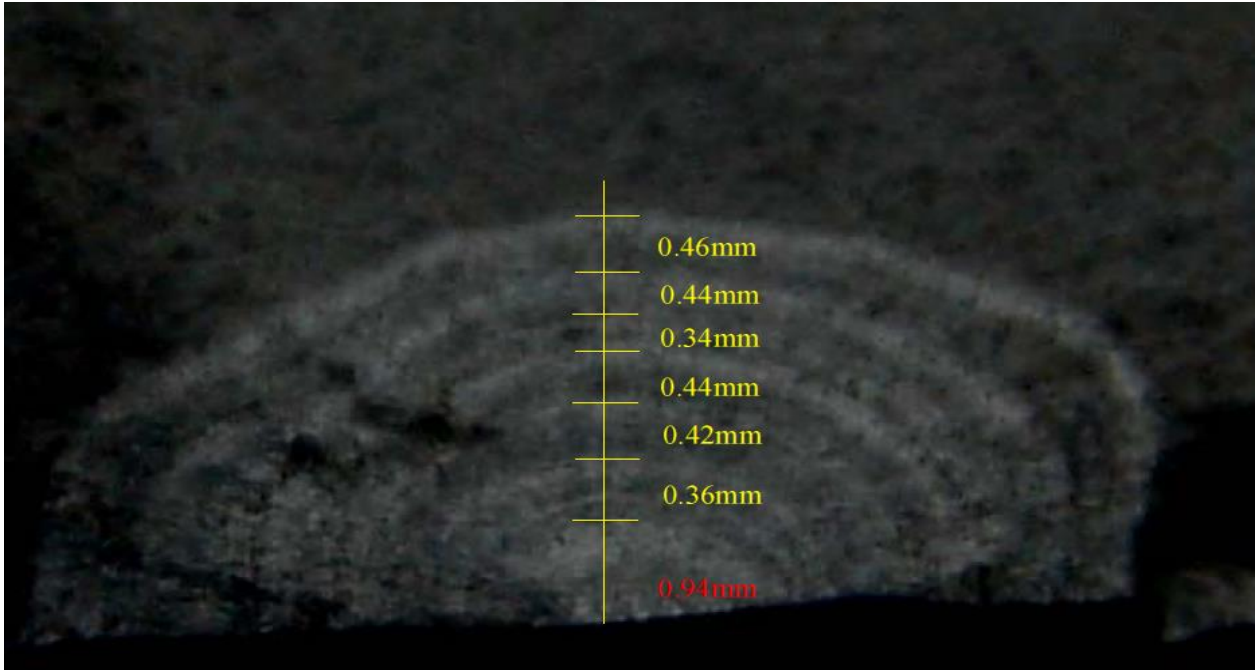


Figure 6. Fracture surface beach marks of crosstube at 20X.

The beach marks shown in figure 8 were further examined at 1000X which revealed fatigue striations shown in figure 9 below. The insert to the lower right side of the photo shows striations magnified further digitally.

The report indicated that the spacing between the striations was measured under the metallurgical microscope using 1000X magnification and was found to vary from 0.75 to 1.0 microns. However, due to the limitations of the optical microscope with regard to the depth of focus, the entire fracture surface cannot be observed as a sharp image as which would have been possible in using a Scanning Electron Microscope (SEM) . Nevertheless, the fatigue striations were clearly visible.

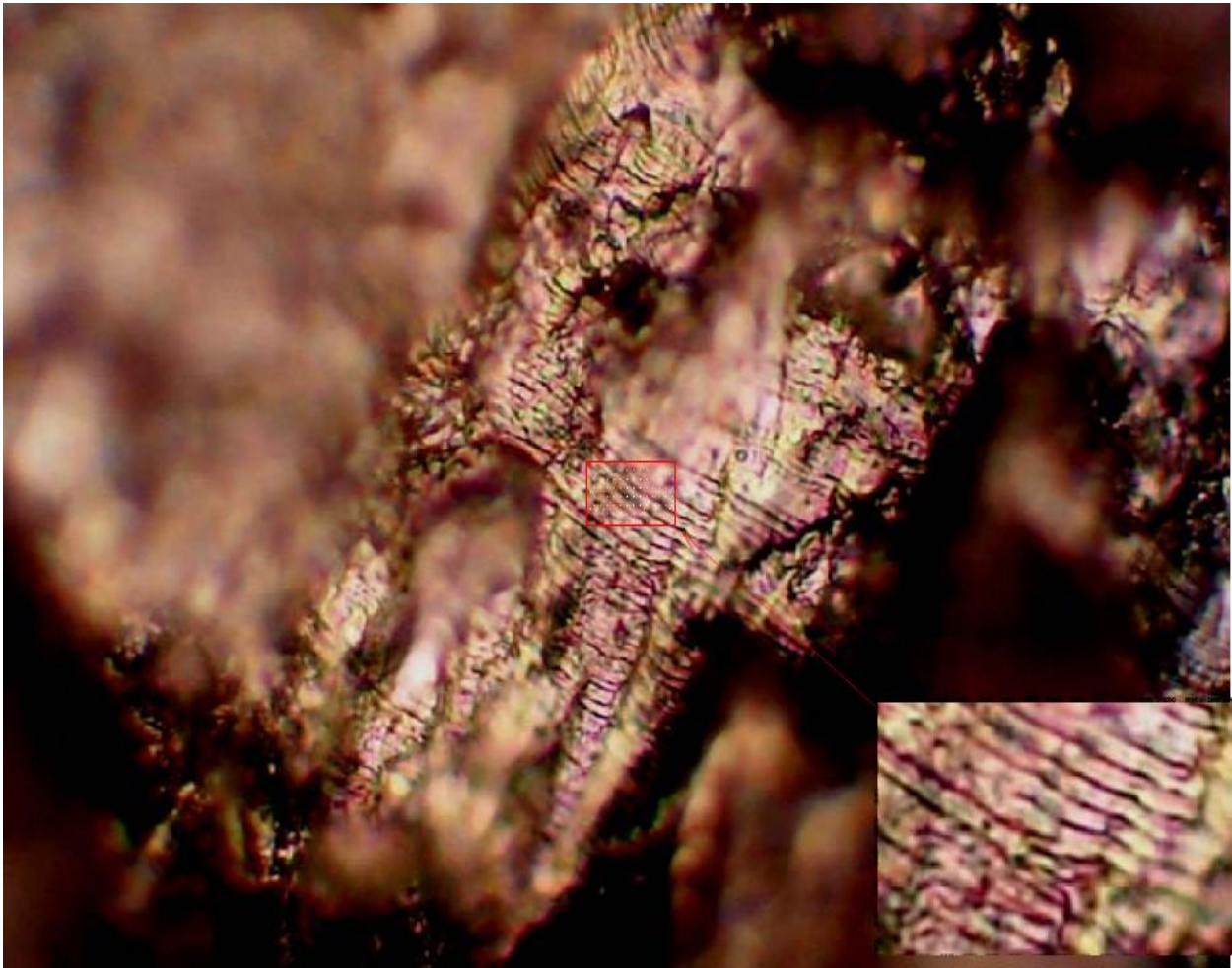


Figure 7. Shows the fracture surface having fatigue striations of cross-tube examined at 1000X.

b. Microstructure Examination

Microstructure examination in a polished condition revealed no abnormalities or secondary cracks on the cross-tube. In figure 10 the fractured surface of the cross-tube can be seen at a magnification of 50x.

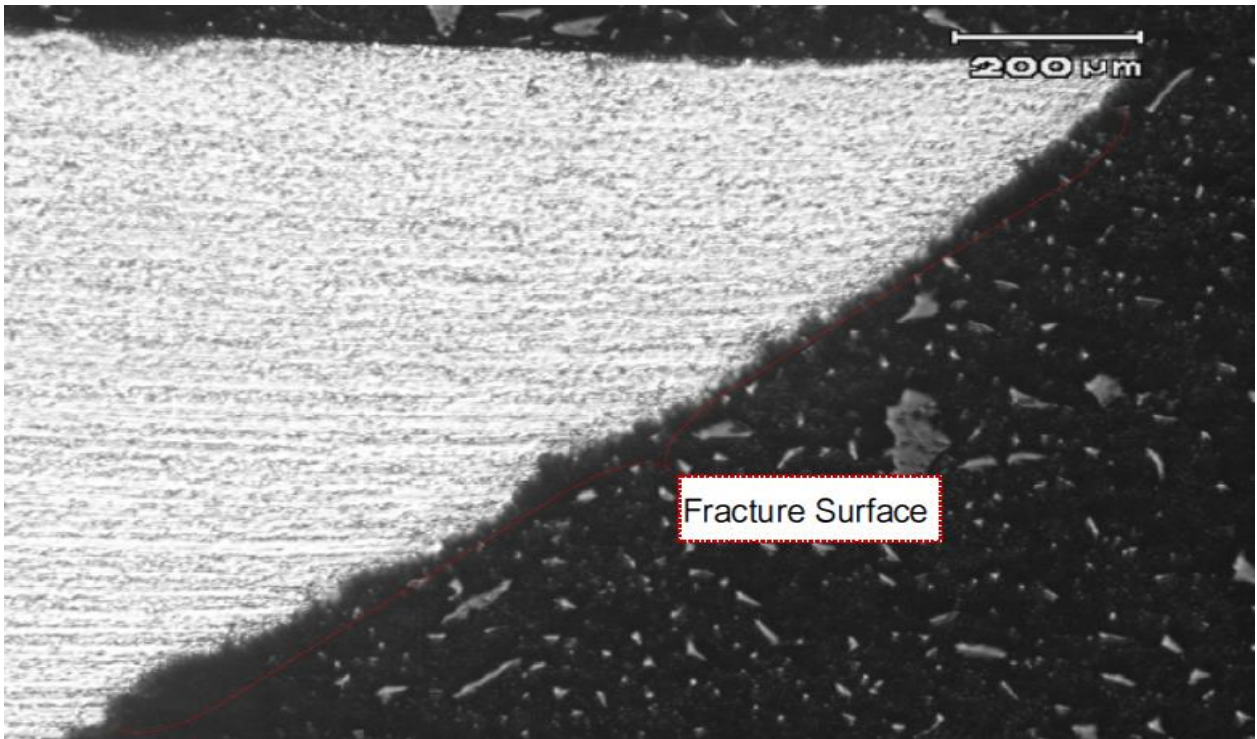


Figure 8. Shows grain pattern adjacent to fracture surface of crosstube ~50X .
Arrow indicates the fracture surface.

Microstructure examination at etched condition has revealed the typical microstructure of Aluminium 7075 Alloy T6 Condition. The figure below shows the microstructure of the crosstube at magnification of 100X.

The metallurgical laboratory examination in Abu Dhabi, UAE, concluded that:

- I the fractured surface of the tube exhibited evidence that is typically found in fatigue failed structures,
- II the fatigue cracks originated from the inner radius of the tube bend
- III the four visible indications were cracks that were later confirmed, following a FPI, which revealed further cracks in the paint striped section of the tube and
- IV there was a large wall thickness variation in the crosstube. However the crack origin was not in the area with the least wall thickness.



Figure 9. Microstructure of the fractured section examined at 100X.

The laboratory report recommended further study employing Scanning Electron Microscopy, at higher magnifications than the ones used by Abu Dhabi the laboratory. Furthermore, the report recommended the inspection method utilized in the field should be capable of detecting the presence of cracks beneath the paint layer of the crosstube.

1.16.2 Tests performed by the landing gear manufacturer

The landing gear manufacturer performed tests on the failed crosstube and provided the crosstube to two independent laboratories, for further investigation. The landing gear manufacturer found²² ... *“a manufacturing abnormality was discovered and*

²³ Landing gear manufacturer failure analysis report (FA-D412-664-1) dated 22 Feb 2012.

determined to be a contributing cause. The subject sample from A6-FLZ was found to have an unusual amount of eccentricity in the crosstube at the point of failure...”.



Photo 15. The ultrasonic equipment used to measure the failed crosstube.

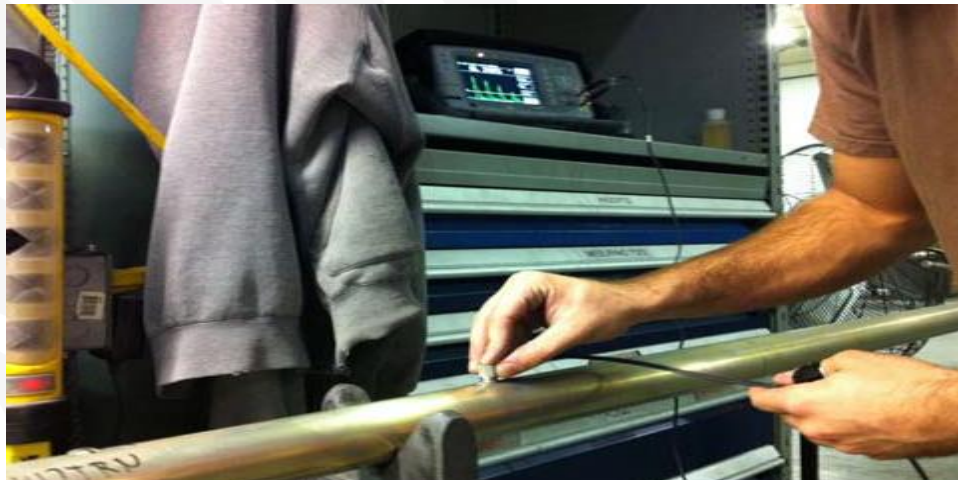


Photo 16. The crosstube thickness measurement utilising ultrasonic equipment.

The landing gear manufacturer indicated that since the introduction of the ultrasonic wall thickness inspection, which was started in August 2011 145 crosstubes were manufactured with no found problems with wall thickness. Of these 145 crosstubes, 18 were of the D412-664-203 type.

In addition the manufacturer researched the friction effect on the crosstubes and indicated that: *“Unimproved landing surfaces have a significant impact on crosstube life since a decrease in the coefficient of friction causes a proportional increase in crosstube stress....conditions approach zero friction, there is a 20% increase in the stress of the Bell 412 high gear aft crosstube.”* Also note that the current material, 7075-T6, starts to yield at 66 ksi, so on a slippery surface (which is

exacerbated by high temperature), the 412 high gear aft crosstube will be yielding at gross weight, which is a big reason why the 412 high gear aft crosstube is so susceptible to fatigue failure. The landing gear manufacturer is less concerned about the D212-664-101 high forward crosstube during these operations. From the table, even at gross weight with no co-efficient of friction, the yield point is not being reached” (see table below).

Co-efficient of Friction	D412-664-203 Crosstube At Gross Weight At Aft CG	D212-664-101 Crosstube At Gross Weight At Fwd CG
0.50 (standard)	62.4 ksi	38.3 ksi
0.25 (slippery)	68.8 ksi	46.2 ksi
0.00 (extreme)	75.3 ksi	54.2 ksi

Table 10. Effect of Friction on Crosstube Stress

1.6.2.1 First Laboratory testing ²³

The landing gear manufacturer forwarded the failed landing gear crosstube to a Canada based independent laboratory. From the report provided by this lab, a scanning electron microscopic examination was performed in order to examine the fatigue fractured surface and to estimate the number of cycles to failure. This was accomplished by measuring the fatigue striation spacing. The lab had no information of the number of landing; however the wall thickness difference was noticed. The laboratory “*In order to estimate the number of cycles to failure, the least damaged side of the fracture was examined using a scanning electron microscope (SEM) to find evidence of fatigue striations and to count them with the intent to estimate the number of cycles to failure. One fatigue striation is considered to be associated with one landing cycle*”.

²⁴ Laboratory 1 Fracture Surface Evaluation G115167 Issue 1 dated 23 September 2011.

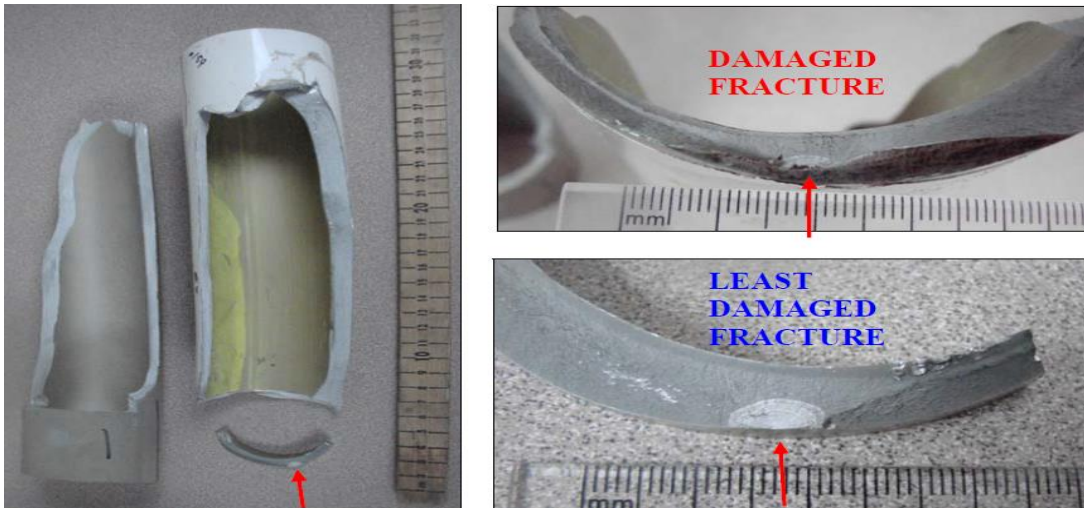


Figure 10. The fractured component as received by the testing facility.

The semicircular shaped bright areas are the fatigue fracture zone (refer to red arrows). The remaining dull grey zone is the final fracture zone.

The fracture surface was cleaned with alcohol in order to remove dirt and foreign particles, while an effort to prevent further damage. Photo 17 below, which illustrates an approximately 3.5 magnification, the red dotted line indicates the locations along which the striation counts were taken and extends from crack initiation at the tube outside diameter to the final fracture zone.

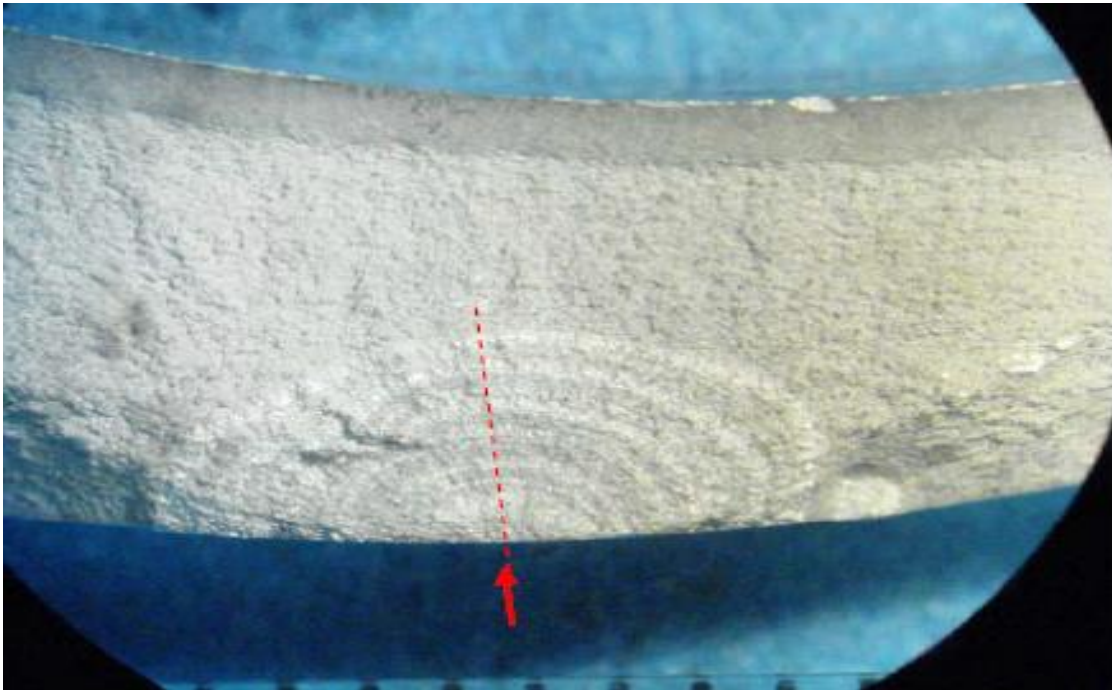


Photo 17. The fatigue portion of the fracture surface is bright with semicircular beach marks.

The laboratory analysis report indicate that : “ *The fatigue portion of the fracture surface was examined using a Jeol JSM-5600 scanning electron microscope (SEM), MII NO B05028, with images and striation counts taken from adjoining fields along the red dotted line.... The area examined extended from the crack origin to the final fracture zone. Ten adjoining images were taken at a magnification of 250 X. Each of these images was examined at magnifications that showed the fatigue striations, typically at 750 X up to 6000 X where required. Fatigue striations were counted over defined distances on each field where present and the striation spacing was then calculated for each field. The size of each field was measured accounting for field overlap and the number of striations per field was estimated by dividing the field size by the striations spacing. The numbers of fatigue striations for each of the 10 fields were added up, with the total being the estimated number of cycles to failure after crack initiation...*”. The report contained the following figures (Secondary Electron Images below figures 13 to 16), which were images on which the striations caused from fatigue could be observed. In addition all the results of the test are summarized in the below table.

Location	Striation Spacing (microns)	Field Size (mm)	Estimated Number of Striations per Field
Field 1 (adjacent to fracture origin)	0.32	0.337	1,091
Field 2	0.44	0.366	832
Field 3	0.57	0.333	575
Field 4	0.78	0.316	421
Field 5	0.88	0.337	364
Field 6	0.54	0.320	624
Field 7	0.66	0.328	479
Field 8	0.35	0.328	951
Field 9	0.39	0.366	938
Field 10 (adjacent to final fracture zone)	0.35	0.337	963
Total Load Cycles Based on Measured Striations	-	total width of fatigue fracture zone: 3.38 mm	7,238

Table 11. Total Load Cycles Based on Measured Striation Spacings

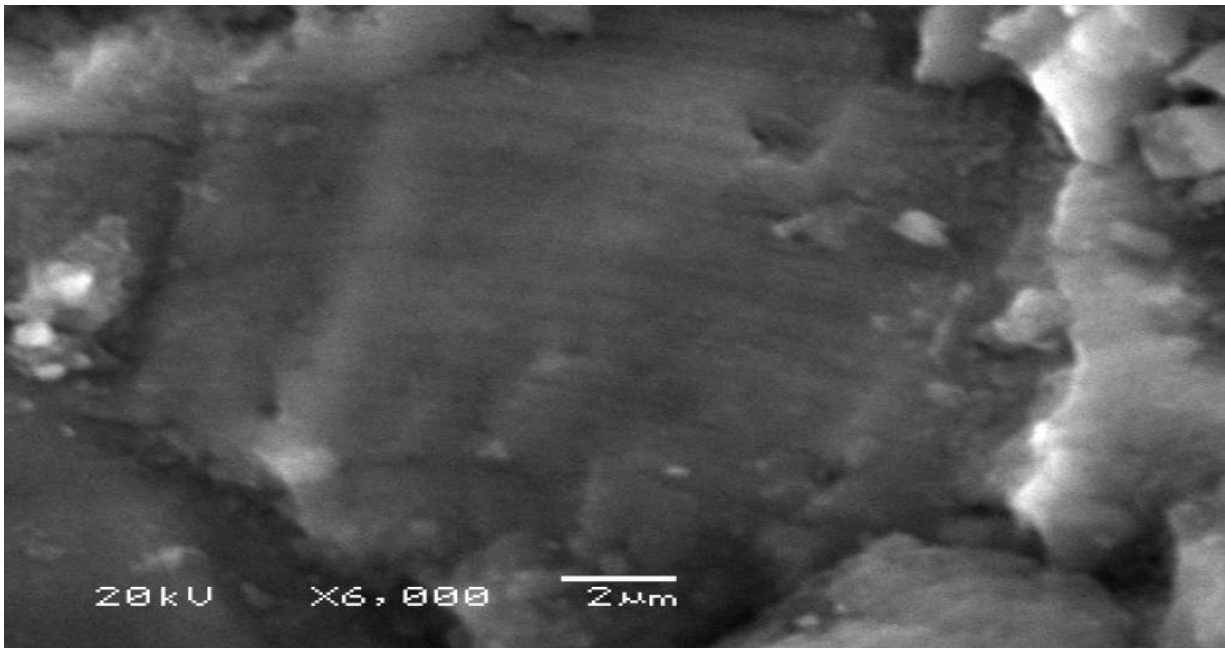


Figure 11. Image showing fatigue striations (parallel features) near the crack origin.

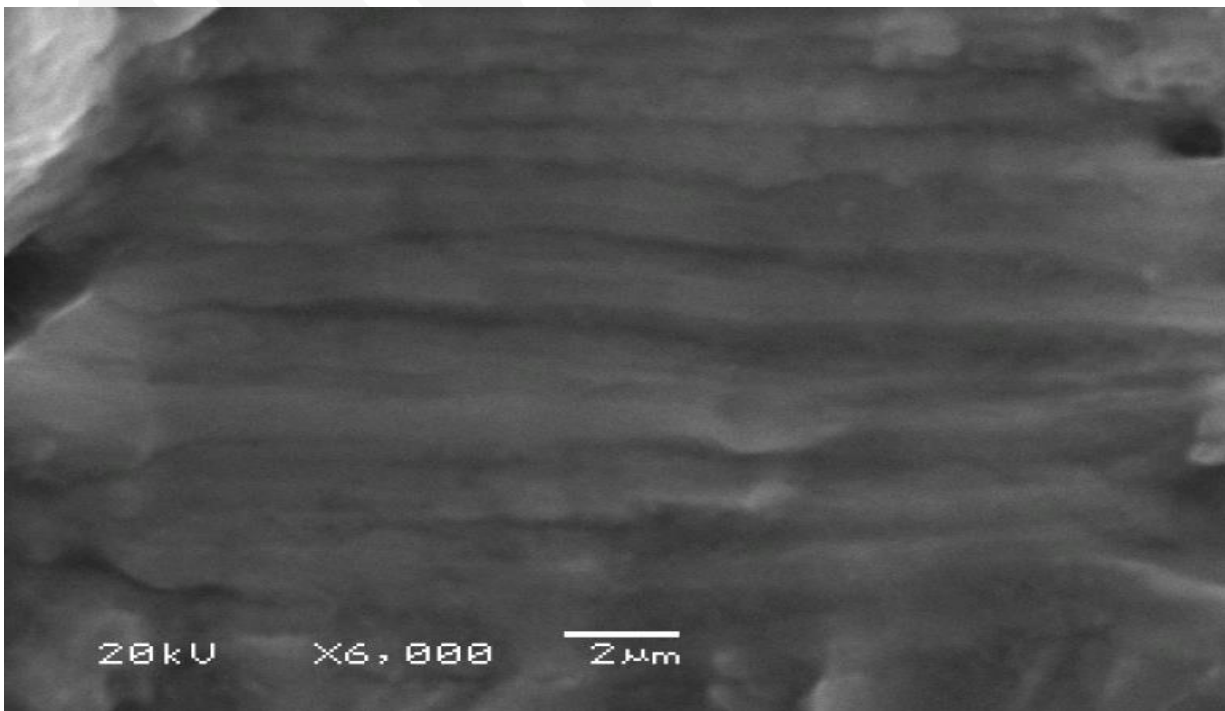


Figure 12. Image showing fatigue striations (parallel features) near the crack origin.

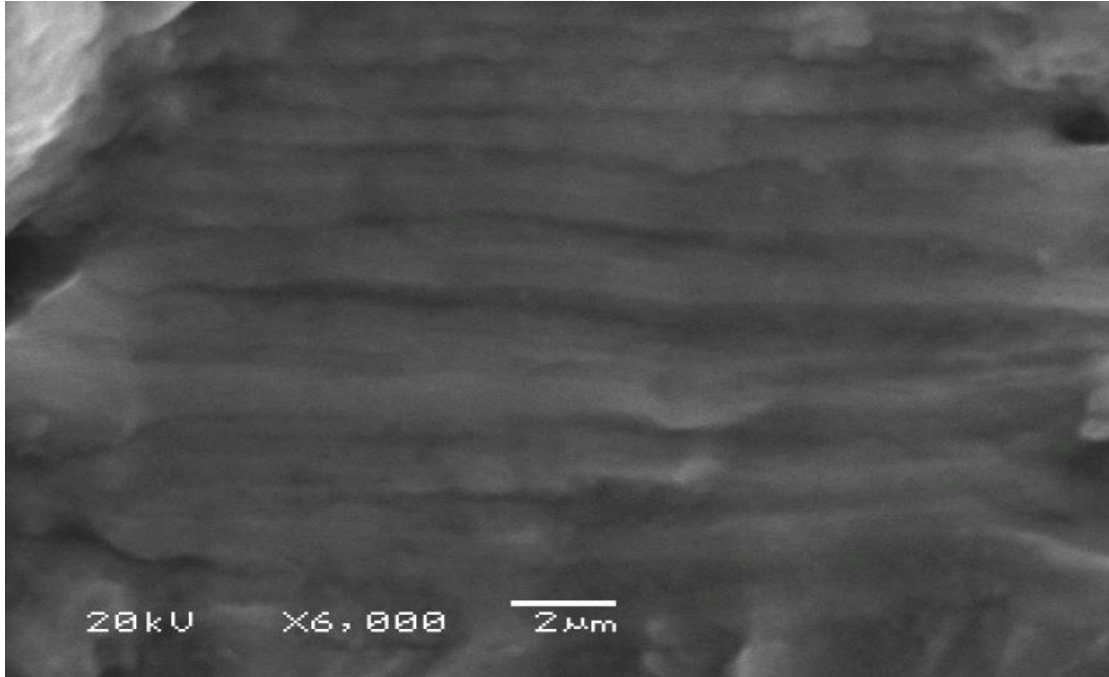


Figure 13. Image showing fatigue striations (parallel features) at the middle of the fatigue fracture zone.

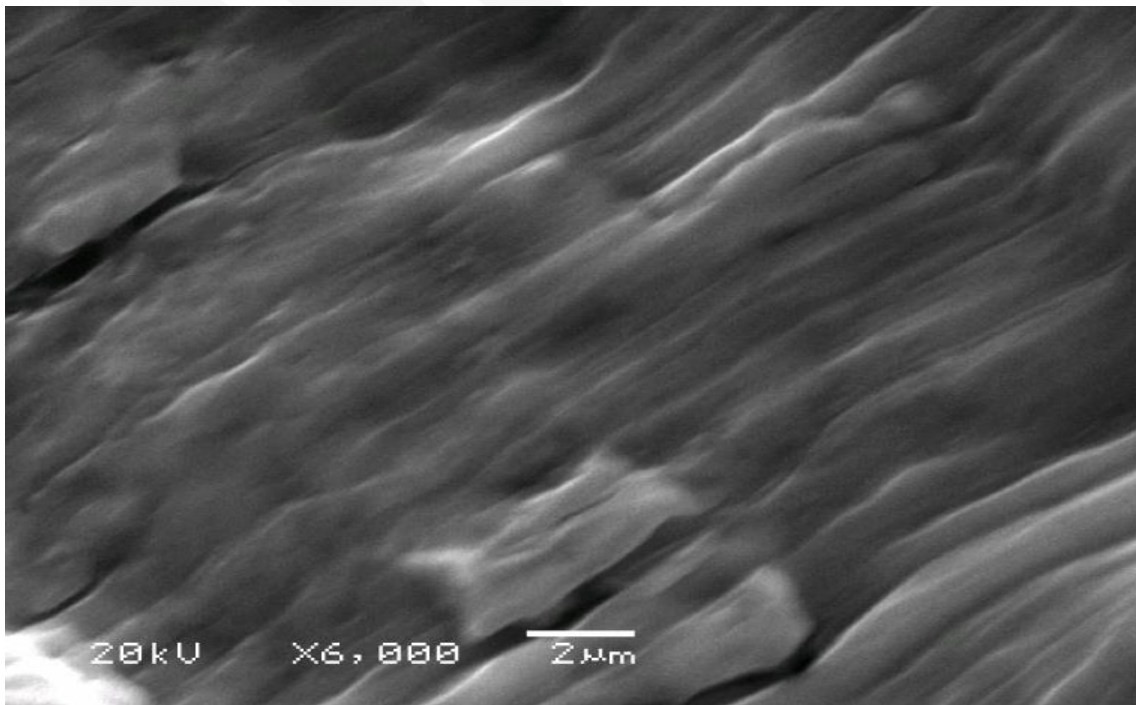


Figure 14. Image showing fatigue striations (parallel features) adjacent to the final fracture zone.

The report concludes that with a 20% error the number of cycles to failure was estimated at 7238, after the initiation of the crack. Furthermore, the report underlines that the used method cannot take into account the number of load cycles prior to the crack initiation.

1.6.2.2 Second Laboratory testing

The second Canada based laboratory²⁴ received the broken parts as per the following photo.

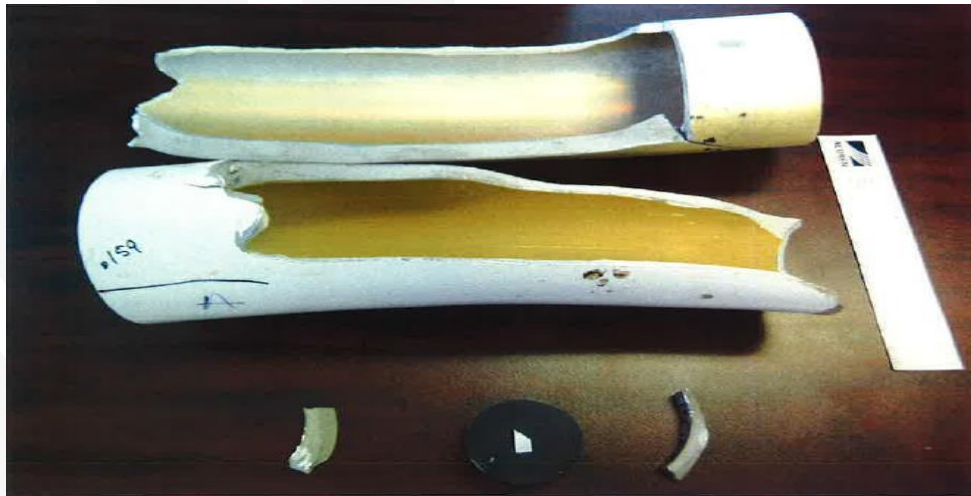


Photo 18. Pieces of the broken component and mount as received by the second laboratory.

²⁴ Project Number 128-12-127, dated 29 January 2012.



Photo 19. The fractured surface

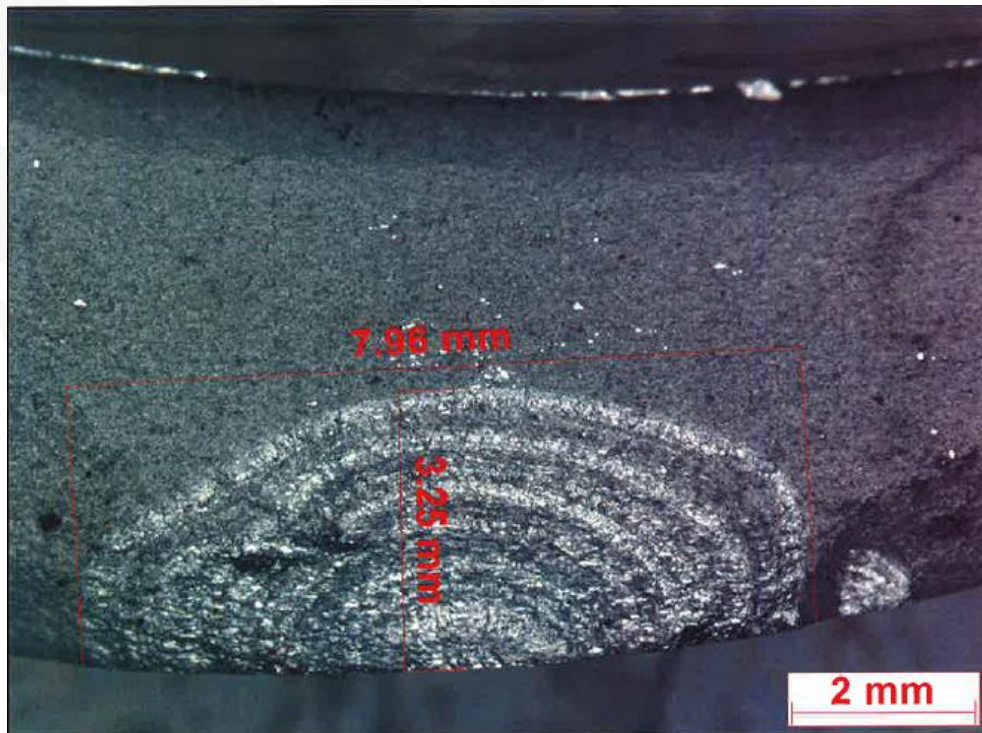


Photo 20. Fatigue crack area.

The laboratory photographed the crack initiation area and took measurements of the thumbnail region under a stereo microscope. Image analysis was also verified prior to making the measurements (see photos 19 & 20 above).

For the striation counting the reports indicates that “*the section that contained the thumbnail area was placed in the SEM chamber. The height of the working distance was 15mm and the tilt was 0°. The acceleration voltage used was 10kV. The path measured in photo 20 was divided into eleven distances and pictures were taken from the initiation point...*”

The following figures are few of the ones contained in the report showing the SEM pictures with striations.

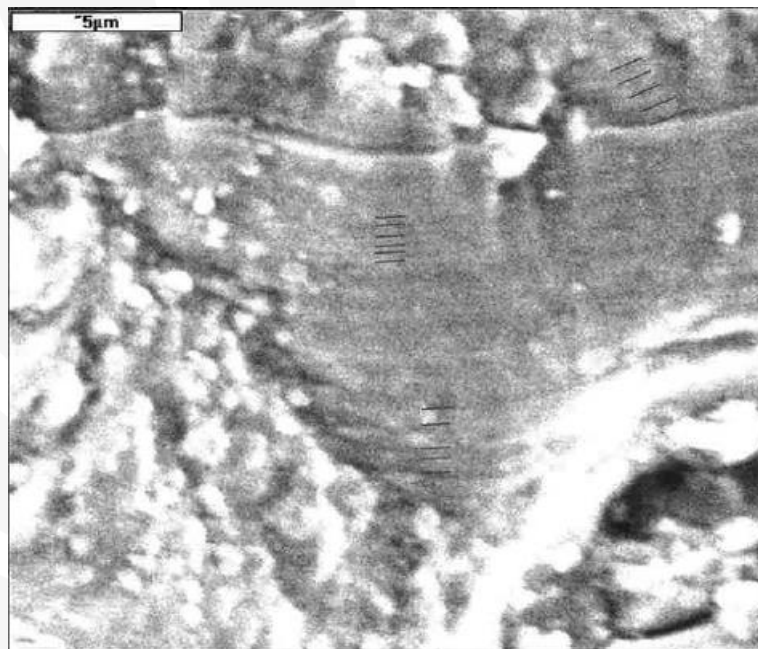


Figure 15. Striations observed at 0.16 mm away from the crack initiation area.

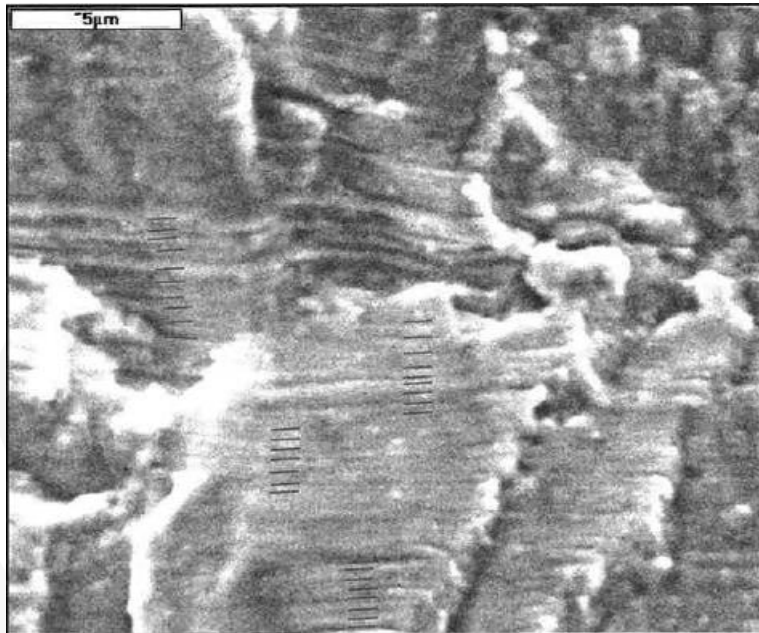


Figure 16. Striations observed at 0.67 mm away from the crack initiation area

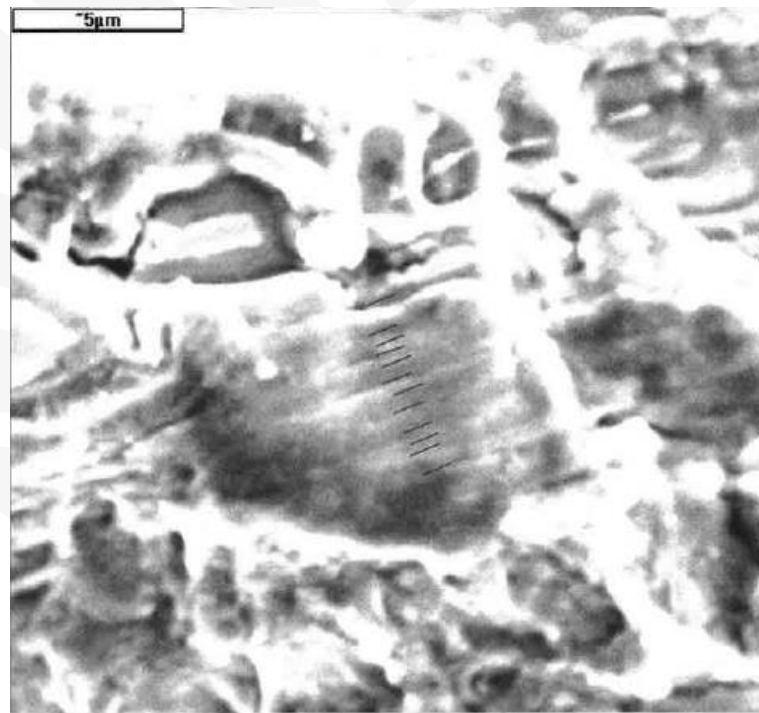


Figure 17. Striations observed at 1.79mm away from the crack initiation area.

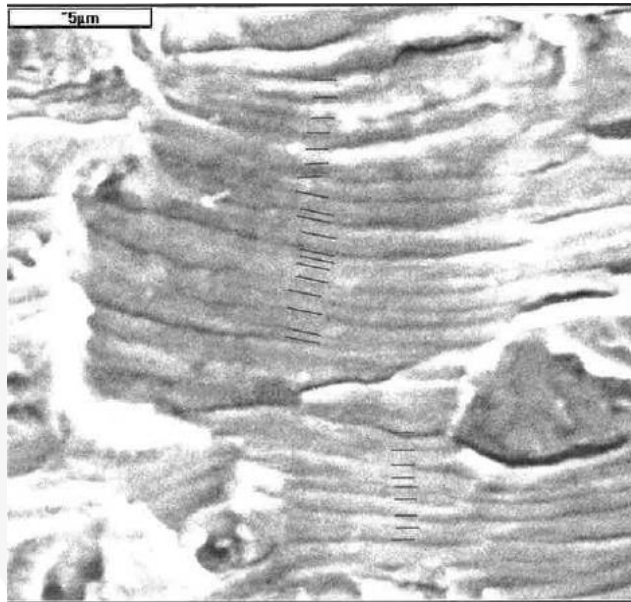


Figure 18. Striations observed at 2.19 mm away from the crack initiation area.

The following figure shows the striation spacing at each distance (see figure 21).

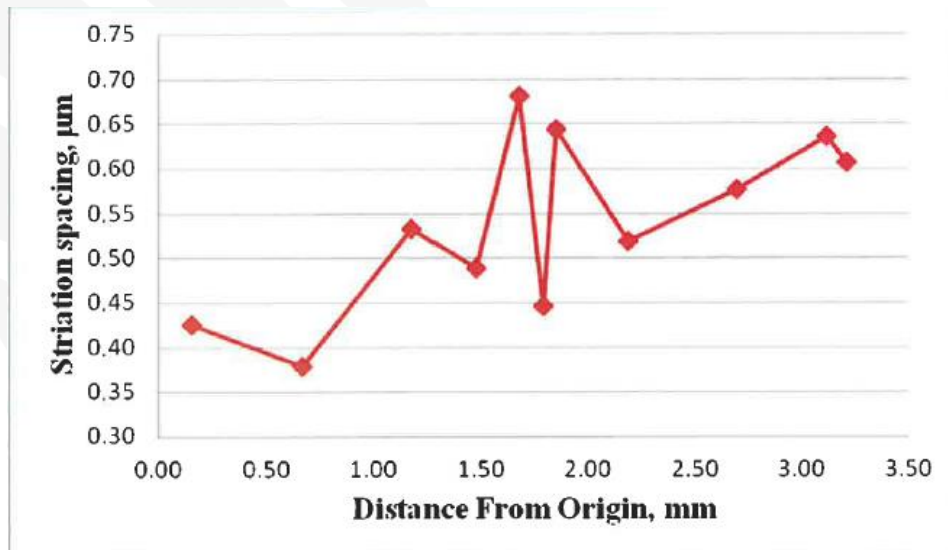


Figure 19. Variation in striation spacing.

Taking into account the total length of the thumbnail, the average striation spacing calculated ($0.5398025\mu\text{m}/\text{striation}$), the report calculates the total number of striations to 6021.



1.17 ORGANIZATIONAL AND MANAGEMENT INFORMATION

The operator is a charter airline and commenced operations in 2006 and is based in Al Bateen Executive Airport, Abu Dhabi, United Arab Emirates. The operator is certified for the carriage of passengers by the UAE General Civil Aviation Authority (GCAA) and operates a fleet of helicopters and business jets.

1.18 ADDITIONAL INFORMATION

1.18.1 Industry Crosstube failures.

The landing gear manufacturer has manufactured 188 D412-664-203 high gear aft crosstubes for the Bell 412. In 2007, a Gulf of Mexico Operator, operating Bell 412 EP helicopters fitted with crosstubes from two landing gear manufacturers, experienced failures which occurred on offshore configured Bell 412EP's. The aircraft were operating at relatively high gross weights in the offshore environment.

In addition, the helicopters were subjected to a high number of landings. Following a landing gear failure in the Gulf of Mexico, the manufacturer performed an investigation which determined that the operating environment was severe and that maintenance practices were questionable. Per Dart SB07-1, the inspection criteria were clarified and operators were reminded of the importance of using the gross weight-towing strap, replacing worn out wear plates, and properly maintaining landing surfaces. There were no changes to the Bell 412EP engineering design or production process as a result.

There have been failures of DAS manufactured D412-664-203 high aft crosstubes for the Bell 412EP under similar operating conditions. Two other Operators encountered failures at 10,495 landings and at 21,057 landings.

Therefore, as summarized in the Table below there have been 5 failures on D412-664-203 crosstubes.

Registration	D412-664-203 B/N	Failure Location	Landings at Failure	Striation Count
XA-UGA	B26675	Off Center	14127	Unavailable
VT-AZO	B25550	Center	21057	6200
unknown	B41153	Center	10495	6700
A6-FLV	LT-09-002581	Center	12598	5589/8314
A6-FLZ	LT-09-004674	Off-Center	11314	7238/6021

Table 12. Summary of all known crosstubes failures



All crosstube failures have been low cycle fatigue failures. The crosstube is designed to yield in service to prevent higher loads being transferred into the airframe and consequently the crosstube operates under extremely high stress. Repeated landings at high weight, and on slippery surfaces, contribute to high stress that the crosstube is exposed to.

In March 2011, the Operator experienced two crosstubes failures (registrations A6-FLV and A6-FLZ). The landing gear manufacturer *“immediately began to investigate the failures. The fatigue analysis for the D412-664-203 aft crosstube was re-performed with a higher load spectrum and a retirement life of 10,000 landings was verified with a knockdown factor²⁵ of 8, which is extremely conservative for a metal structure. Furthermore, a crack growth analysis was performed and it was demonstrated that the crosstube could withstand over 4000 cycles to failure after detection of a crack. As a result of this analysis, a retirement life of 10,000 landings was established for the D412-664-203 aft crosstube with a mandatory LPI at 7500 landings as outlined in SB11-2”*.²⁶

The landing gear manufacturer submitted the crosstubes to independent laboratories for striation counts. Based on the high striation counts, the landing gear manufacturer indicated that they are *“confident that if the crosstube is not found to be cracked after 7500 landings, it will be safe to continue operating for 2500 cycles until the crosstube is replaced at 10,000 landings.*

*Since the introduction of these stringent airworthiness limits, no abnormalities or incidents have been reported. After consultation with Transport Canada, the content from SB11-2 was incorporated into ICAD212-664 at Rev. 7.”*²⁷

1.18.2. Service Bulleting (SB) 11-2

SB 11-2 was issued by the landing gear manufacturer on the 25th April 2011 informing the operators that : *“Due to unexpected failures of 0412-664-203 high gear aft crosstubes at a low number of landing cycles, a life limit of 10000 landings has been established for all D412-664-203 high gear aft crosstubes. Crosstubes that already exceed the life limit must be replaced immediately”*.

In addition, all landing gears that have accumulated more than 7500 landings should be removed stripped of paint, and LPI inspected. In case any crosstube is found

²⁶ Safety factors and knockdown factors are examples of measures used to compensate for uncertainty during the design process. See : Effects of Structural Tests on Aircraft Safety at : <http://www2.mae.ufl.edu/nkim/Papers/paper48.pdf>

²⁷ Failure Analysis report dated 22 February 2012 (FA-D412-664-1) page 4.

²⁸ Failure Analysis report dated 22 February 2012 (FA-D412-664-1) page 5.



without any crack, can be returned to service but replaced at 10000 landings maximum without re-inspection.

1.18.3 A6-FLV Aft Crosstube Failure tests in the UAE

1.18.3.1 Brief on the event

The aircraft, a Bell 412EP, registration A6-FLV, operated by Falcon Aviation Services, made an uneventful approach and landing on the helideck of Wellhead Tower PC03 at Zakum Field, United Arab Emirates, at approximately 0720UTC on 16th March 2011. It was intended to embark ten passengers and some equipment. After nine passengers had boarded, the aircraft suddenly settled and adopted a nose high attitude. Subsequent examination of the aircraft by the crew showed that the undercarriage aft crosstube had failed.

1.18.3.2 The tests and examinations.

The failed undercarriage aft crosstube of A6-FLV was subjected to metallurgical examination at a laboratory in the United Arab Emirates²⁸. Tests were carried out in order to verify the crosstube material and to determine the nature of the failure mechanism. The following tests and evaluations were undertaken;

- a) Material Identification
- b) Visual Examination
- c) Eddy Current Inspection
- d) Fluorescent Penetrant Inspection
- e) Hardness survey
- f) Microscopic and Microstructure (Scanning Electron Microscope) Examination

1.18.3.3 A6-FLV Aft Crosstube Failure tests performed by the landing gear manufacturer

The landing gear manufacturer arranged for two independent laboratories to perform analysis on the failed crosstube with the following results:

A. Test performed on the 23rd of September 2011

As per the test report the test method used to test the fracture faces was visual and then using stereomicroscope MII NO B05649. Following rinsing with alcohol in order

²⁹ Test was performed at the ADAT Metallurgical Laboratory, Abu Dhabi, UAE, April 2011(F- 1239).



to remove any contamination and/or dust, further damage was prevented. Multiple crack origins were detected, along with some impact damage at the crack area. The inspection revealed that the fatigue portion of the fracture surface was bright with semicircular beach marks. “The fatigue portion of the fracture surface was examined using a Jeol JSM-5600 scanning electron microscope (SEM), MII NO B05028. The width of the fatigue fracture zone from initiation site to final fracture was measured to be 5.84 mm using the scanning electron microscope’s micrometer. The width of the fatigue fracture zone was then divided into 10 equally sized zones from the middle of which striation counts were taken at magnifications up to 6000X. Fatigue striations were counted over defined distances on each field where present and the striations spacing was then calculated for each field from which the number of stress cycles (striations) per field were calculated. The numbers of fatigue striations for each of the 10 fields were added up, with the total being the estimated number of cycles to failure number of fatigue striations per field associated with this damaged region was assumed to be the same as for the field immediately adjacent to it. The test results are presented in the Table below. Refer to Figures 3, 4 and 5 for representative images of the observed fatigue striations. In many areas the fatigue striations were poorly defined with superimposed finer parallel features. These were presumed to be slip lines due to slip along the crystallographic planes at the crack front when the crack was propagating and were ignored in the evaluation. Slip lines can be difficult to distinguish from fatigue striations. after crack initiation. It should be noted that the fracture surface in the vicinity of the crack origin was heavily oxidized, obscuring the fatigue striations at this location. The number of fatigue striations per field associated with this damaged region was assumed to be the same as for the field immediately adjacent to it. The test results are presented in the Table below. In many areas the fatigue striations were poorly defined with superimposed finer parallel features. These were presumed to be slip lines due to slip along the crystallographic planes at the crack front when the crack was propagating and were ignored in the evaluation. Slip lines can be difficult to distinguish from fatigue striations.”

Distance from crack origin (mm)	Location	Striation Spacing (microns)	Field Size (mm)	Estimated Number of Striations per Field
0	Crack origin	-	-	-
0.29	Field 1	0.63 ²⁹	0.584	927
0.88	Field 2	0.63	0.584	927
1.46	Field 3	0.91	0.584	642
2.04	Field 4	1.16	0.584	503
2.63	Field 5	1.11	0.584	526
3.21	Field 6	1.20	0.584	487
3.80	Field 7	1.18	0.584	495
4.38	Field 8	1.41	0.584	414
4.96	Field 9	1.75	0.584	334
5.55	Field 10	1.75		334
5.84	final fracture zone to fatigue zone interface	-	-	-
	Total Load Cycles Based on Measured Striations	-	total width of fatigue fracture zone: 5.84 mm	5, 589 Estimated Total Striations

Table 13. Total Load Cycles Based on Measured Striation Spacings

The report indicates that various factors may affect the measured striation spacing. One factor is abrasion damage occurring during the failure that may obscure the finer

²⁹ No well-defined striations observed due to oxidation damage. Striation spacing assumed the same as for Field 2.

fracture surface detail. Furthermore, the method used cannot account for the number of load cycles prior to crack initiation.

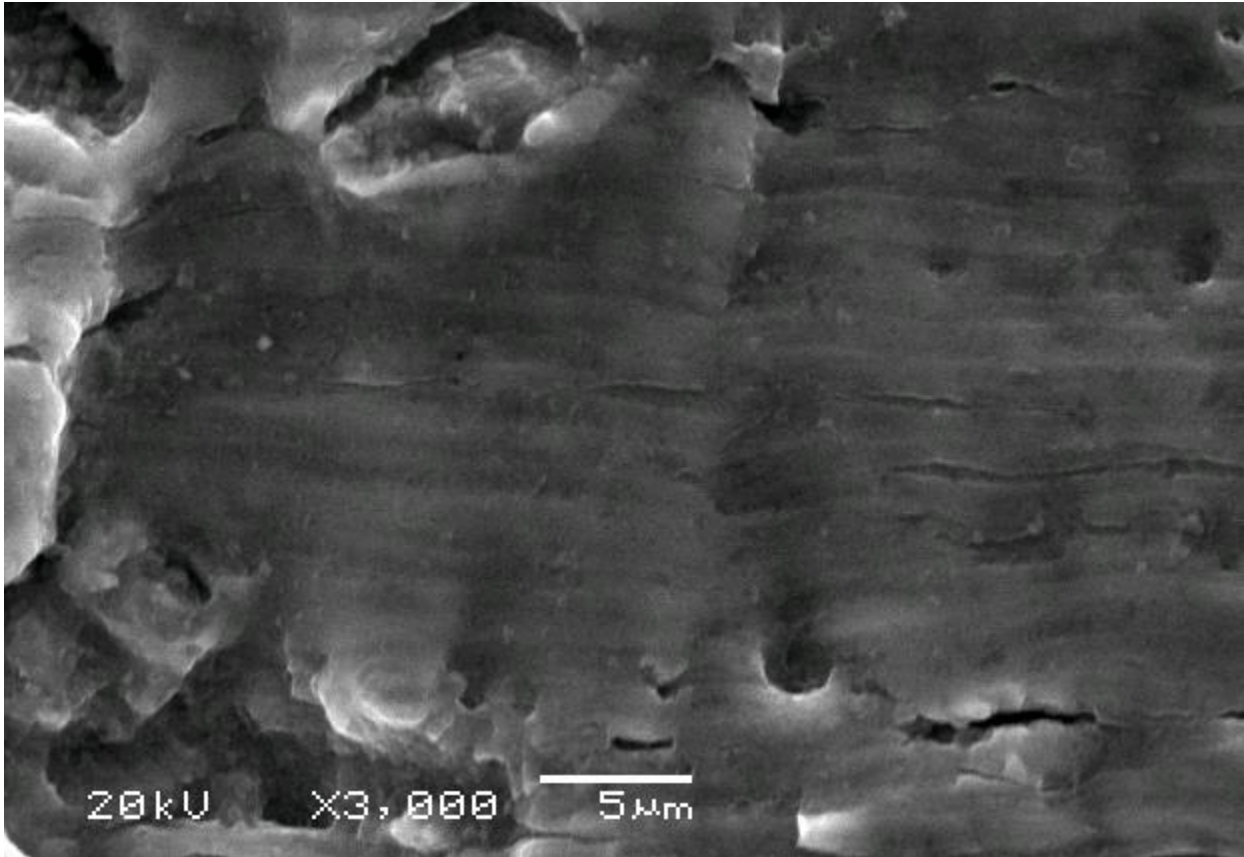


Image 1 Showing fatigue striations (parallel features) at the middle of the fatigue fracture zone.

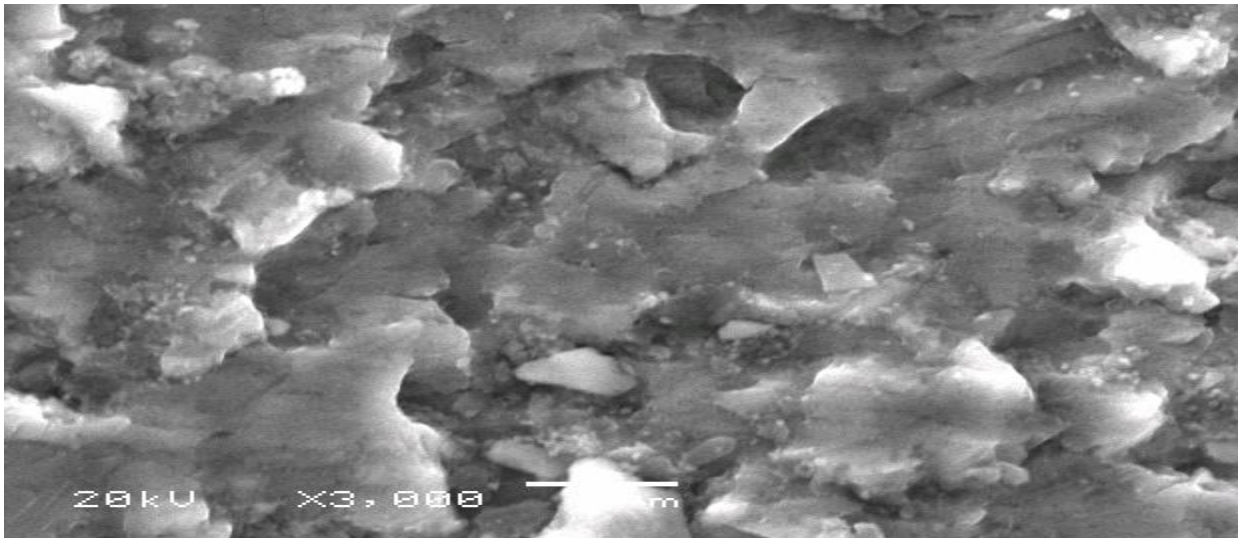


Image 2. Faint fatigue striations (parallel features) of a field near the crack origin (field 2).

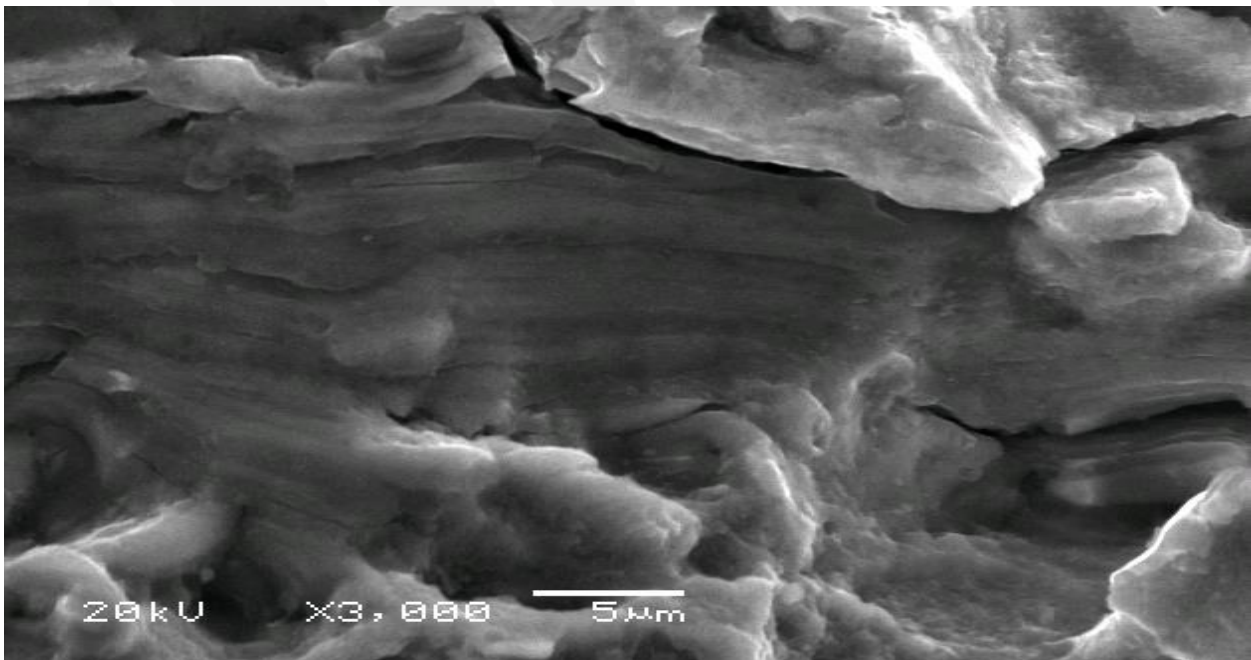


Image 3. Fatigue striations (parallel features) adjacent to the final fracture zone.

B. Second Test performed by the landing gear manufacturer³⁰

Following the first test, the landing gear manufacturer accomplished an additional test, which was performed by another independent laboratory, which was employed to “*assess the fatigue crack growth quantitatively by employing striation counting*”³¹.

The laboratory performed a visual examination and measured the section of the crosstube received. The dimensions were found to be approximately 90.4 mm (~3.56 inches) in diameter, 164 mm (~6.46 inch) in length (the longest portion) with a 16.4 mm (~0.65 inch) wall thickness. In addition, the report stated that the observed beach marks suggested a fatigue crack initiation, which had colour differentiation comprising bright grey, signifying the cracked beachmarks and the dull grey signifying the remaining area (see photos 5 and 6).

The laboratory indicated that the figure 22 “*shows the thumbnail area removed from the mating fracture surface. All the measurements were made on this sample. The thumbnail region was photographed under the stereo microscope and measurements were made on the picture. Image analysis measurements were verified prior making the measurements*”.

In addition the section was further cleaned with alcohol in ultrasonic bath for approximately half an hour and replica rubber material was used to clean further the thumbnail, which was used to measure the striations. Thereafter the cleaned section was placed in a scanning electron microscope (SEM) chamber, with a working distance height of 15mm and a tilt of 0°.

The report indicates that the “acceleration voltage was 20 kV (10 kV and below the image did not appear good).” The path measured in Figure 2 was divided into five approximately equal distances and pictures were taken after the initial 0.88 mm from the initiation point.

³¹ Report dated 04 Dec 2012, under project number 128-11-2984.

³² Report dated 04 Dec 2012, under project number 128-11-2984 “*Introduction and Scale*”.

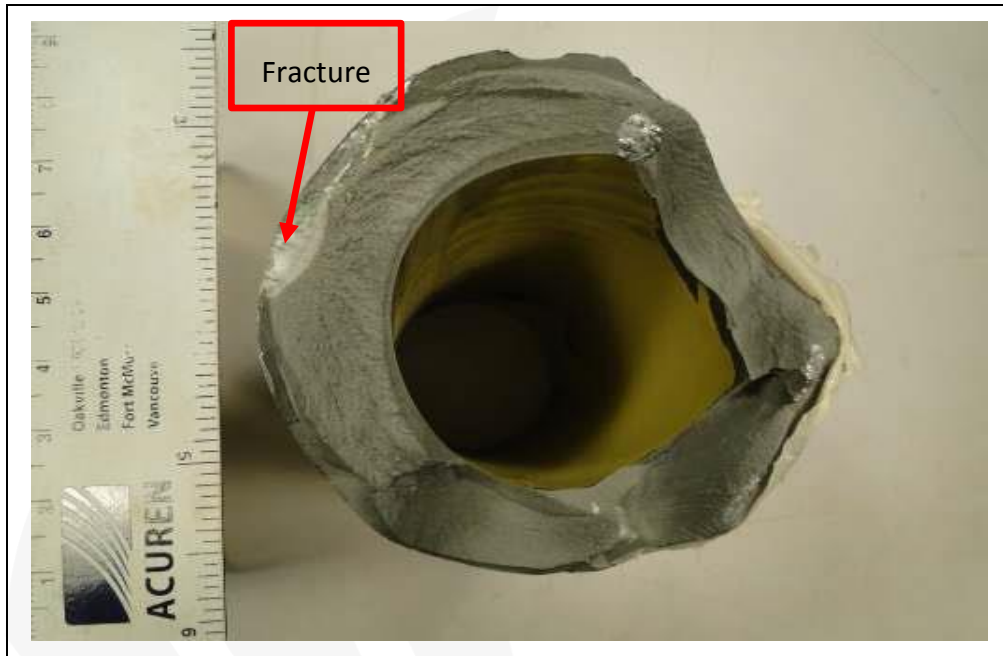


Photo 21. Fractured surface

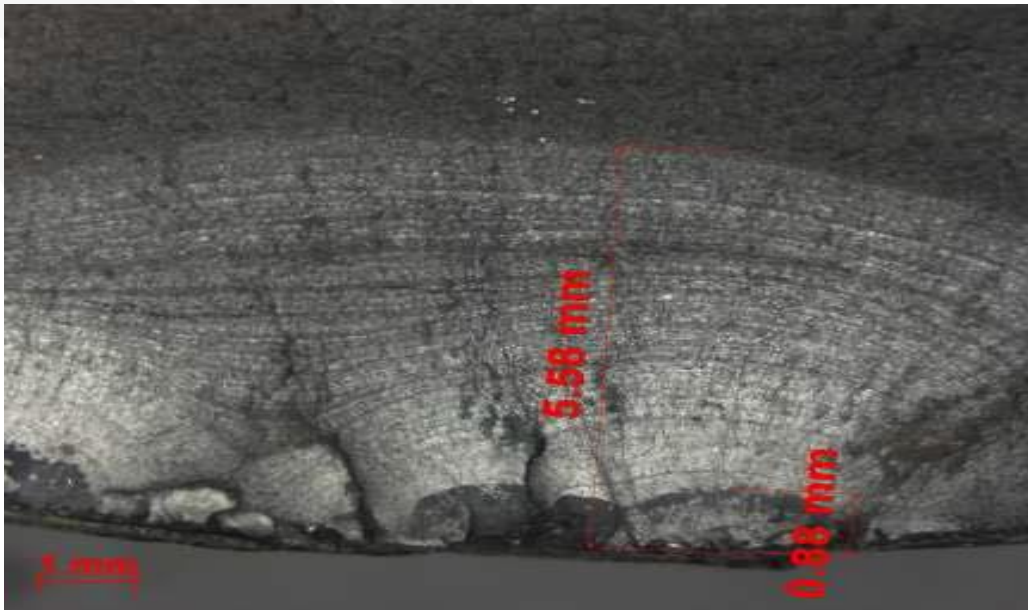


Figure 20 Fatigue Cracked Area

The striations observed were counted at a measured distance. The following table shows the distance from the crack origin to the area where the striations were counted and the average striation spacing in that area (see table 7). In addition the laboratory showed the striation spacing at each distance (see figure 23) and calculated the total number of ...”striations over the 5.58 mm length counted to be approximately 8,314”.

Distance From Origin, mm	Striation spacing, µm
1.76	0.65677966
2.76	0.46610169
3.6	0.91101695
4.52	0.67796610
5.44	0.64406780
Average	0.67118644

Table 14 Striation spacing in different areas

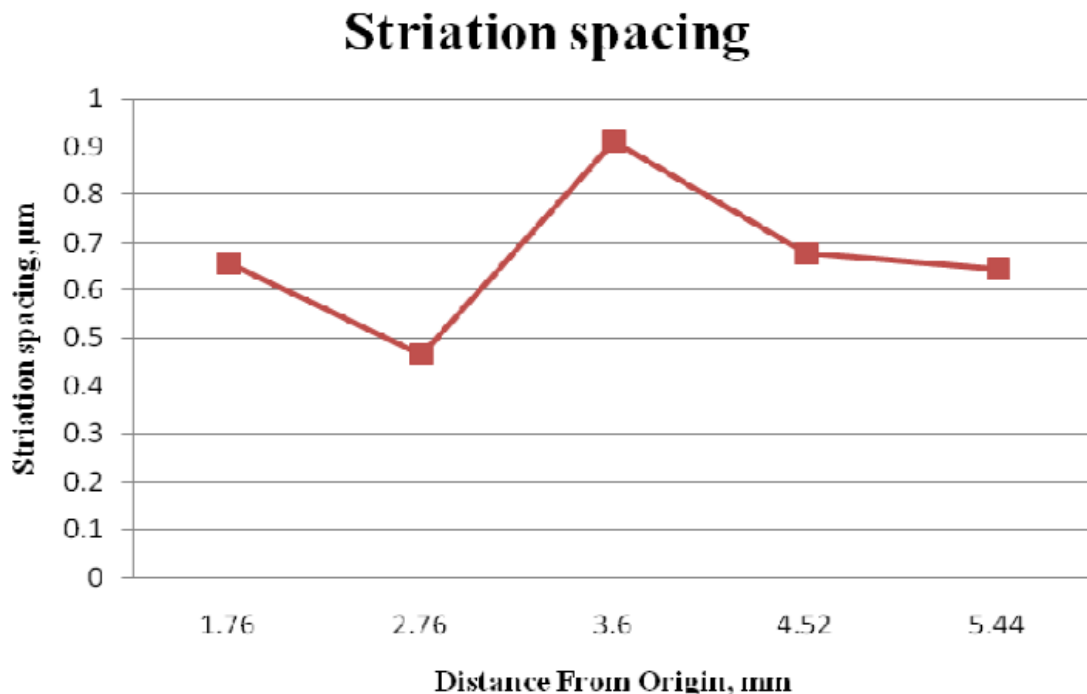


Figure 21 Variation in Striation spacing.



1.18.4 Previously Reported Bell 412EP Undercarriage Aft Crosstube Failures

The Team reviewed two incidents of failed crosstubes manufactured by the same manufacturer, which were prior to this occurrence investigation involving A6-FLZ. These mishaps are discussed in more detail below.

1.18.4.1. Failure of Undercarriage Aft Crosstube of Aircraft XA-UGA

In the case of aircraft XA-UGA the aft crosstube failed at three locations; RBL 30, RBL 10 and LBL 30. The site of the primary failure location is unknown. Examination of the fracture surfaces showed evidence of thumbnail-shaped regions of flat transverse fracture i.e. beach marks, at the fracture origins. This aircraft operated in the Gulf of Mexico transporting passengers to and from oil rigs. No injuries resulted from the incident.

The investigation found that the operator was not using the gross weight towing strap and that the wear plates were badly worn. In addition, the landing surface was slippery. Resulting from this incident the manufacturer published Service Bulletin 07-1.

1.18.4.2. Failure of Undercarriage Aft Crosstube of Aircraft VT-AZO

A second Bell 412EP, VT-AZO, carrying out operations related to the off-shore oil industry in India, suffered an undercarriage aft crosstube failure.

The undercarriage aft crosstube failed near the centre support. There was evidence of 0.8 cm deep thumbnail shaped beach marks at the fracture site. The aircraft had just landed at Tapti Oil Rig when the crosstube failed. No injuries occurred either to passengers or crew as a result of this incident.

The investigation report produced by the Indian DGAC recommended that more thorough visual inspection of the crosstube was required during maintenance. The manufacturer published Service Bulletin 10-1.

1.18.4.3 Further Crosstube failures

Three further reports of undercarriage aft crosstube failures have been reported involving crosstubes manufactured by a different supplier. In these cases, the failures occurred at 10723, 11894 and 15336 landings.



1.18.5 Transport Canada Airworthiness Directive number CF-2012-14R1

Transport Canada issued an Airworthiness Directive under the title “*Crosstubes – Life Limitation*” with an effective date 22nd of May 2012 which established the life limitation of 10,000 landings.

1.18.6 Federal Aviation Administration Airworthiness Directive number 2013-16-16

With an effective date 17 September 2013, the Federal Aviation Administration adopted a new AD for the Bell Helicopter Textron Model 412, 412CF and 412EP helicopters with a certain high gear aft crosstubes installed, which are the same as the occurrence crosstube. The FAA added a life limit of 10,000 landings to the crosstube and removed from service any crosstubes with more than 10,000 accumulated landings. The AD summary informs that the AD was prompted by five separate reports of crosstubes failures, aiming to *prevent failure of the crosstube* and subsequent collapse of the landing gear.

1.18.7 The Regulatory Framework.

1.18.7.1 International Civil Aviation Organisation

ICAO has issued two volumes of Annex 14 to the Convention on International Civil Aviation under the title Aerodromes. Annex 14 Volume II³² deals with Heliports, has six chapter and two appendices. The body of the Annex contains ISARPs on Heliport data, physical characteristics, obstacle environment, visual aids and the heliport services.

(A) ICAO Document 9261 *Helicopter Manual*³³

This document contains seven chapters and two appendices and offers guidance to States for their certificate holders on helicopter landing areas issues.

³² Fourth Edition July 2013. This edition incorporates all amendments adopted by the Council prior to 28 February 2013 and supersedes, on 14 November 2013, all previous editions of Annex 14, Volume II.

³³ Doc 9261-AN/903. Third Edition 1995.



“The manual deals with three principal types of heliports, namely, surface level heliports, elevated heliports and helidecks which may be located on offshore installations or ships. The manual not only enlarges upon some of the specifications in Annex 14, Volume 11, as necessary, but also provides guidance on aspects not dealt with in the Annex, e.g. site selection, winching areas, underslung load operating areas, etc.”

In more detail it provides direction on offshore helideck installations:

2.3.1.8 *“The helideck shall have an over-all coating of non-slip material and all paint markings on the surface of the helideck shall be made of non-skid materials. A wide variety of suitable materials are available commercially and information on which materials would be best applied in particular cases should be obtained through the appropriate authority in each individual State.*

2.4.2.5 *The FATO³⁴ shall have an over-all coating of non-slip material and all paint markings on the surface of the FATO shall be made from non-skid materials. A wide variety of suitable materials are available commercially and information on which materials would be best applied in particular cases should be obtained through the appropriate authority in each individual State”.*

The document also refers to Helidecks on ships:

3.2.4.2.7 *“It is particularly important, due to the ship's motion, that the surface of the FATO be skid resistant for helicopters, and the heliport as a whole, slip resistant for personnel. The provision of a landing net is also desirable”.*

1.18.7.2 UAE GCAA Regulations CAR PART IX

The UAE Regulator has published reference material for aerodrome certification in the form of Civil Aviation Regulations (CAR) PART IX³⁵. Part IX is issued by the Authority in pursuit of its obligations to ensure conformity with accepted international regulations (including the State Safety Programme) and standards at aerodromes of the State and

³⁴ As per ICAO DOC 9261 (paragraph 1.2.1.1) Final approach and take-off area (FATOs): A FATO is an area over which a helicopter completes the approach manoeuvre to a hover or landing or commences movement into forward flight in the take-off manoeuvre

³⁵ Dated December 2010, complete revision



to follow up their acceptance in coordination with local aerodrome authority/operators. The document contains specifications, which are based upon the Standards and Recommended Practices of Annex 14 Volume 1 and 2 and Annex 15 to the Convention on International Civil Aviation in so far as they have been adopted by the United Arab Emirates. In section 1.1.5 the publication states that *“An aerodrome certified in accordance with Civil Aviation Regulation Part IX will be suitable for use by helicopters. Presently there is no section dealing exclusively with the criteria for helicopter operations. Proposals for the design of helicopter heliports and helidecks shall be in accordance with ICAO Annex 14 Volume 1 and 2”*.

In more detail in chapter 2, under the title certification process it is stated that *“Any other Aerodrome Operator may apply to the Authority for an Aerodrome Certificate.*

Note: Offshore helidecks and emergency heliports³⁶ are not covered within these Regulations³⁷.

Moreover there is no special provision of related to helidecks nor any definition.

APPENDIX 16

HELIPORTS

16.1 This Appendix applies to heliports that are required to or wish to be certified.

GCAA NPA No. 09/2013 CIVIL AVIATION ADVISORY PUBLICATION (CAAP) 71 HELIDECKS (OFF-SHORE)

On 18th July 2013, the General Civil Aviation Authority published a notice of proposed amendment (NPA) following a review of the regulatory and safety oversight of aerodromes³⁸ within the UAE. This review has included aerodromes and heliports / helidecks.

³⁷ In accordance with CAR PART IX (complete revision December 2010) heliport is An aerodrome or a defined area on a structure intended to be used wholly or in part for the arrival, departure and surface movement of helicopters.

³⁸ UAE CAR-PARTIX (complete revision December 2010) paragraph 2.1.2.

³⁹ The GCAA defines as aerodrome: defined area on land or water (including any buildings, installations and equipment) intended to be used either wholly or in part for the arrival, departure and surface movement of aircraft.



The introduction to the NPA states that due to the review, an evaluation has been undertaken of the requirement for helidecks with reference to ICAO Annex 14 Volume II (Heliports) and the approach to provide safety oversight for offshore helidecks in the UAE. *“This NPA is introducing a new CAAP as detailed in Section B to this NPA and is also introducing changes to Civil Aviation Regulations as detailed in Section A to this NPA. The aim of this CAAP is to provide guidance to operators of helidecks; it also aims to introduce a process for safety oversight. The proposed CAAP should ensure compliance with the UAE Civil Aviation Law; Civil Aviation Regulations (referenced below) and conformance with the international standards of ICAO Annex 14, Volume I (Aerodromes) and Volume II (Heliports).*

CAR PART IV, OPS 3.220 (Commercial and Private Air Transportation: Helicopters): *Authorisation of Heliports by the Operator: “An operator shall only authorise use of heliports that are adequate for the type(s) of helicopter and operation(s) concerned”.*

*The **implementation** of the GCAA regulatory and safety oversight process will however, commence later, (a date will be provided by a GCAA publication, following the publication of the CAAP and the amended Civil Aviation Regulations). CAAP 71 will be subject to change as a result of ICAO Amendment Number 5 to ICAO Annex 14 Volume II which, subject to adoption by the ICAO Council, which became applicable on 14th November 2013”.*

The NPA introduces amendments to the GCAA aerodromes regulations (CAR PART IX). The changes relate to heliport³⁹ certification or aircraft (helicopter) landing area acceptance and regulatory oversight of heliports. It also provides information for the implementation of the regulations, service fees of aerodrome or heliport certificate holders and holders of Aircraft or Helicopter Landing Area.

The proposed CAAP will provide guidance and policy information to all helideck⁴⁰ operators of UAE off-shore installations. The publication provides guidance and information for helidecks process for GCAA acceptance and certification, physical characteristics of helidecks and shipboard, safety net and structural design, obstacle

⁴⁰ The GCAA defines as **Helicopter** as an aerodrome or a defined area on a structure intended to be used wholly or in part for the arrival, departure and surface movement of helicopters.

⁴¹ When GCAA utilizes the term ‘helideck’ refers to all helicopter landing areas on fixed or floating offshore facilities used for the exploration of oil and gas. For helicopter landing areas on vessels the term ‘shipboard heliport’ may be used in preference to ‘helideck’.



restriction and removal, visual aids on marking and markers, aeronautical lights and the last chapter on rescue and fire fighting facilities.

In chapter 3 under the title physical characteristics: Helidecks paragraph 1.10 states that *“The surface of the FATO shall be skid-resistant to both helicopters and persons and be sloped to prevent pooling of water.”* The following note states that *“Guidance on rendering the surface of the FATO⁴¹ skid-resistant is contained in the Heliport Manual (Doc 9261).”*

1.18.7.4 The UK CAA - CAP 437 Standards for Offshore Helicopter Landing Areas⁴²

The UK CAA, Safety Regulation group published CAP 437 “Standards for Offshore Helicopter Landing Areas” in February 2013, a publication that provides *“the criteria applied by the CAA in assessing the standards of offshore helicopter landing areas for worldwide use by helicopters registered in the United Kingdom. The 7th Edition has been revised to incorporate the full and final specification for the helideck lighting scheme comprising perimeter lights, lit Touchdown/Positioning Marking Circle and lit Heliport Identification ‘H’ Marking. It also includes new ICAO Standards and Recommended Practices relating to offshore helidecks and shipboard heliports that are due to be adopted in March 2013. For the first time requirements were included in the 6th Edition for the design of winching area arrangements located on wind turbine platforms. With the benefit of lessons learned through various industry forums attended since 2008 these sections have been reviewed and updated to represent current best practice.”*

The publication contains reference for offshore helicopter landing sites. In more detail following an introduction the publication has the helicopter performance considerations and the factors affecting their capabilities, a description of the landing areas and the physical characteristics, such as design, size, surface, hoist, winching safety nets among other issues. The reference document then continues into

⁴² GCAA defines Final approach and takeoff area (FATO) as a *“defined area over which the final phase of the approach manoeuvre to hover or landing is completed and from which the take-off manoeuvre is commenced. Where the FATO is to be used by helicopters operated in performance class 1, the defined area includes the rejected take-off area available”*.

⁴³ Seventh edition incorporating Amendment 01/2013, Dated February 2013, source : <http://www.caa.co.uk/application.aspx?catid=33&pagetype=65&appid=11&mode=detail&id=523>
The CAP may be found at : <http://www.caa.co.uk/docs/33/CAP437.pdf>



providing reference on visual aids, helideck rescue and fire fighting facilities and landing areas, along with miscellaneous operational standards. The last four chapters contain fuelling facilities guidance along with helicopter landing areas on vessels and helicopter winching areas on vessels and on wind turbine platforms.

In Chapter 3, page 12, the document provides guidance for the offshore landing area surface. In more detail is stated that *“The landing area should have an overall coating of non-slip material and all markings on the surface of the landing area should be finished with the same non-slip materials. Whilst extruded section or grid construction aluminium (or other) decks may provide adequate resistance to sliding, they should be coated with a non-slip material unless adequate friction properties have been confirmed by measurement... It is important that adequate friction exists in all directions and in worst case conditions, i.e. when the deck is wet. Over-painting friction surfaces on such designs with other than non-slip material will likely compromise the surface friction. Suitable surface friction material is available commercially”*.

1.19 USEFUL OR EFFECTIVE INVESTIGATION TECHNIQUES

There were neither useful nor effective investigation techniques used during the investigation.

2. ANALYSIS

2.1 GENERAL

No previous similar failure of the undercarriage aft crosstube had occurred in the operators' experience, although two prior similar failures had been reported involving other operators.

All of the operator's Bell 412EP helicopters are equipped with a High Crosstube Undercarriage which is required to enable the installation of a skid mounted Emergency Floatation System with its automatically deployable life raft. This installation is approved by Transport Canada (Supplemental Type Certificate (STC) SH01-9), EASA (STC IM.R.S.01304) and the FAA (STC SR01298NY).

The Captain was Pilot Flying [PF] and the First Officer was the Pilot Monitoring [PM]. The Captain's report stated that the aircraft performed the assigned flight into their destination from where they picked up passengers. All available sources confirmed that the flight was uneventful. After landing and the passenger embarkation, whilst the



helicopter was ready to depart, the aft landing gear crosstube fractured and the aircraft adopted a significant nose high attitude.

In addition, during the abrupt movement the crew heard a loud noise indicating that an abnormal condition had occurred. The Captain opened the door and looked outside to try to determine what had occurred. He noticed that the helicopter aft fuselage was in close proximity to the helideck surface. The crew immediately shut down the engines and the passengers and crew safely disembarked the aircraft. There was no other prior indication of failure and the crew was unaware of any other malfunctions or prior indications that could lead them to suspect the failure that they experienced. The engineering and maintenance records did not indicate nor included any maintenance action that could lead to any kind of suspicious activity. Therefore, no indication of the imminent failure was given to the crew or to the maintenance personnel involved in the dispatch of the helicopter.

Later, the crew inspected the lower aft fuselage of the helicopter and they noted that the undercarriage aft crosstube has sheared. The aircraft came to rest on the right hand side (RHS) aft jacking point.

2.2 Pilot and maintenance reports for previous flights.

Both pilots reported that the landing was normal. Nothing unusual, such as a hard landing, was reported during any of the flights prior to the Incident flight, nor was any previous maintenance issue recorded that could potentially indicate any possible problem involving the undercarriage. It is therefore evident that both crewmembers and the maintenance personnel had no earlier indication of the coming fracture and had no possibility of knowing the potential landing gear failure. In addition the Operator followed the manufacturer's and GCAA's maintenance instructions and had no prior indication of the failure, and inspected the aircraft in accordance with the provided inspection intervals.

2.3 Analysis of previous undercarriage crosstube failures.

The undercarriage crosstube is designed to yield in service to prevent higher loads from being transferred into the airframe and consequently operates under extremely high stress. Repeated landings at high weight and on slippery surfaces contribute to high stress in the crosstube.

There have been three reported failures of the D412-664-203 aft crosstube at 14127, 21057 and 12598 landings. These failures have occurred to aircraft performing landings at high weights on platforms at extremely high frequency.



2.4 Tests / Examination

As previously indicated the crosstube had four cracks which were visible on the inner radius surface of the crosstube. In addition, the eddy current inspection revealed more cracks parallel to the ones, which were visible. External damage, scoring or impacts were not noticed on the tube surface. However, the cracks would have been very difficult to be identified by an engineer, during routine inspections, because of their location. That is why the removal of the crosstube is necessary, although costly, to ensure the condition of the material, thus the safety of the operation. Ideally, maintenance personnel should be able to identify such cracks without removing the tubes from the helicopter, as soon as possible.

Fractured surfaces exhibited beach marks / striations originating from the inner radius surface of the bend. In addition, the ultrasonic examination revealed that there was different wall thickness level of the tube. This dissimilar thickness level was also observed. Although the landing gear manufacturer indicated in its failure report⁴³ that the different crosstube wall thickness is a "...onetime event. Since the introduction of the ultrasonic wall thickness inspection process that started in August 2011, there have been 145 crosstubes manufactured with no anomalies regarding wall thickness. Of these 145 crosstubes, DAS has manufactured 18 x D412-664-203 crosstubes with no anomalies". The issue remains that there is a possibility that a tube with the same manufacturing abnormality to be currently in operation. That is why the manufacturer should take every possible precaution to remove, in case it is found, such a crosstube, as the wall thickness difference was identified as a contributing factor. The failed tube was found to have an unusual amount of eccentricity at the point of failure. The landing gear manufacturer has taken safety actions in the meanwhile and has eliminated the possibility of another similar tube to go to a helicopter, as ultrasonic inspections after the machining process and quality controls were put in place to prevent any possibility of reoccurrence.

Fracture surfaces revealed a thumbnail region of fatigue beach marks/striations. The Investigation team performed test in the UAE that could provide the possibility of revealing the cracks while the landing gear tube was still attached to the aircraft, therefore without removing it from its position. In addition, the Investigation Team's effort, both with paint and without paint, within its capabilities, was to reveal an inspection method that could provide the assurance of an inspection method used in the field with the ability to detect presence of cracks beneath the paint layer. The Investigation Team's effort was undertaken in order to provide solid evidence of a method that could be used in the field of operations without highly specialized

⁴³ FA-D412-664-1, pages 5 and 6 of 6, dated 22nd February 2012.



personnel, equipment and recourses. However as revealed the Team's efforts, within its capabilities, as described in the relevant section, could not provide any guidance for such a method. Therefore, more efforts have to be undertaken, in order to verify that such a method exists and then ensure that it could be used easily in the field. Nevertheless, the AD issued limiting the lifetime of the landing gear has currently solved the landing gear failures. However, the aviation industry always benefit from better methods applied. In any case, the oversight Authority of the manufacturer could review the possibility of investing resources to ensure that potential future specified maintenance inspections, intended to detect material fatigue, are practical and effective.

During the course of this investigation the Investigation Team was informed by the landing gear manufacturer was working on the design of an improved aft crosstube; however the Team received some information on the issue and efforts should continue to ensure that the improvements are materialized.

2.5 The fractured crosstube occurrences experienced by the Operator.

Reviewing the data and information gathered from the fractured crosstube events in the UAE (A6-FLV and A6-FLZ) which occurred during March 2011, one may identify the following similarities:

- Similar total airframe time (within 160 hours),
- Similar total landings (within 1263 landings),
- Similar average landings per flight hour (6.18/flight hour),
- Both A6-FLV & A6-FLZ had just embarked passengers (9 A6-FLV / 11 A6-FLZ),
- Fracture occurred on right hand side of crosstube (outboard of pivot fitting),
- Similar aircraft operating weight at the time (within 500 pounds).

However, the landing surface requirements of the two helidecks were significantly different:

• A6-FLV

Well head Tower PC03, the landing surface (steel) was in good condition with a very good covering of non-slip paint over the entire deck.

•A6-FLZ

ZWAP, the landing surface (steel) in poor condition. There is no effective non-slip surface application. The actual landing area is very shiny there for the deck friction between the helicopter and steel deck is minimal.



Review of the operating conditions, the legislative and regulatory framework under which offshore operations are performed in the UAE helidecks, revealed that the GCAA has issued a notice of proposed amendment (NPA No 09/2013, CAAP 71) to its regulations⁴⁴, which is described in paragraph 1.18.7.2 (UAE Regulations) of this report. In addition, the current UAE regulations contain aerodrome provisions. Thorough review of the notice of proposed amendment reveals that the proposed publication is an enhancement to the existing regulations providing detail guidelines to all UAE certificates holders, utilizing offshore helidecks. The publication examines the existing and potential development of the specific aviation industry, in order to ensure its safe growth. However, it refers to a relevant ICAO Helicopter Manual⁴⁵, a summary of which may be reviewed in paragraph 1.18.7.1 (International Civil Aviation Organisation) of this report. A detail review of this Document indicates that ICAO allows the Civil Aviation Authority of the country to provide local guidelines in the form of the following wording:

“Therefore restrictions may be imposed on helicopter operations by the appropriate aviation authority”.

Or

“A wide variety of suitable materials are available commercially and information on which materials would be best applied in particular cases should be obtained through the appropriate authority in each individual State”.

The wording is necessary as the ICAO provides guidelines that individual State has to utilize locally. Although reference to ICAO documents may create ambiguity, the GCAA NPA also refers to a UK publication (UK CAA CAP 437)⁴⁶, a summary of which may be found in paragraph 1.18.7.4 of this publication. The UK publication is indented to provide guidelines to offshore helicopter landing areas applied to helicopters registered in the United Kingdom, but used worldwide. The publication provides detailed information and safe solutions to certificate holders.

Detailed review of the available documents indicates that the UAE NPA publication does not have clear guidelines for the material to be used on the surface of the helidecks, although the UK and the ICAO publications have identical wording, which provides the way and the condition of the material to be used on helidecks' surface. The non-slip material that both documents describe, furnishes the helicopters' landing

⁴⁵ [http://www.gcaa.gov.ae/en/ePublication/_layouts/GCAA/ePublication/DownloadFile.aspx?Un=/en/ePublication/admin/Library%20Pdf/Notice%20of%20Proposed%20Amendment%20\(NPA\)/NPA%2009-2013%20-%20CAAP%2071%20HELIDECKS%20\(OFF-SHORE\).pdf](http://www.gcaa.gov.ae/en/ePublication/_layouts/GCAA/ePublication/DownloadFile.aspx?Un=/en/ePublication/admin/Library%20Pdf/Notice%20of%20Proposed%20Amendment%20(NPA)/NPA%2009-2013%20-%20CAAP%2071%20HELIDECKS%20(OFF-SHORE).pdf)

⁴⁶ ICAO Document 9261 Helicopter Manual

⁴⁷ CAA - CAP 437 Standards for Offshore Helicopter Landing Areas



gear need, for a safer helideck surface, which will dampen the shocks sustained and reduce the effects of the cyclic loading on the crosstube. Although helidecks in the UAE have this provision, having the regulations in place will ensure that, over a certain period, all helidecks will be accordingly equipped with this non-slip material.

That will ensure the safety of all helicopter occupants at all times, as fracture of the crosstube in different situation could had catastrophic consequences. In case the fractured landing gear pivots around the skid, then, there is a possibility, a remote possibility, for a dynamic rollover⁴⁷. As most cases of dynamic rollover occurs when the pilot attempts to lift the helicopter into a hover while focused on the ground close to the aircraft rather than on the distant horizon, which is not always clearly available on an offshore helideck. However, there were cases⁴⁸ when a dynamic roll over occurs when the helicopter approaches an offshore landing platform.⁴⁹

That is why the GCAA will have to make all possible efforts to ensure that the surface of all helidecks, used to offshore operations, are equipped to the industry's best practices, standards and recommended practices. The surface of the specific helideck was poor and slippery adding pivot forces and stress on the landing gear. It is logical to assume if such a condition exists in one offshore helideck, there is a possibility for other helidecks to have the same conditions. That is why the GCAA should undertake

⁴⁸ <http://www.youtube.com/watch?v=-9GW8OShlc>

⁴⁹ <http://www.youtube.com/watch?v=XWpeFY53qWM>

⁵⁰ Dynamic rollover is the helicopter's lateral rolling tendency, when lifting off the surface. For dynamic rollover to occur, some factor has to first cause the helicopter to roll or pivot around a skid, or landing gear wheel, until its critical rollover angle is reached. Then, beyond this point, main rotor thrust continues the roll and recovery is impossible. If the critical rollover angle is exceeded, the helicopter rolls on its side regardless of the cyclic control corrections made. Dynamic rollover begins when the helicopter starts to pivot around its skid or wheel. Whatever the cause, if the gear or skid becomes a pivot point, dynamic rollover is possible if the pilot does not use the proper corrective technique. Once started, dynamic rollover cannot be stopped by application of opposite cyclic control alone.

Sources:

Flight Standards Service. Rotorcraft Flying Handbook: FAA Manual H-8083-21. Washington, DC: Flight Standards Service, Federal Aviation Administration, U.S. Dept. of Transportation, 2001. ISBN 1-56027-404-2.

http://helicopterflight.net/dynamic_rollover.htm

<http://heliinstructor.com/app/download/1769770904/Dynamic+rollover.pdf>

http://www.dynamicflight.com/aerodynamics/dynamic_roll/

<http://www.stlouishelo.org/School%20of%20Aviation%20Safety%20Dynamic%20rollover.pdf>

<http://bestaviationarticles.com/?p=20>

<http://heliinstructor.com/app/download/1769770904/Dynamic+rollover.pdf>



a UAE wide approach in order to verify the condition of all offshore helidecks, in order to ensure that safety surface standards are uniformly met.

3. CONCLUSIONS

3.1 GENERAL

From the evidence available, the following Findings, Cause and Contributing Factors were made with respect to this Serious Incident. These shall not be read as apportioning blame or liability to any particular organisation or individual.

3.2 FINDINGS

- 3.2.1 The aircraft was certified, equipped, airworthy and maintained in accordance with existing regulations and approved procedures.
- 3.2.2 The Flight Crew members were properly licensed, medically fit and qualified for the flight and adequately rested in accordance with existing regulations.
- 3.2.3 The Flight Crew members complied with the flight and duty time regulations.
- 3.2.4 The pilots actions and statements indicated that their knowledge and understanding of the aircraft systems was adequate.
- 3.2.5 The Flight Crew first became aware of a problem when they heard a loud noise as the final passengers boarded and the aircraft suddenly adopted a nose up attitude.
- 3.2.6 Nothing unusual was reported during the flights immediately prior to the incident, nor was any previous maintenance issue recorded, that indicated any potential problem involving the undercarriage.
- 3.2.7 The operator complied with the undercarriage manufacturer's STC ICA and other periodic visual inspections.
- 3.2.8 Prior to the incident the undercarriage aft crosstube Part Number D412-664-203 did not have an assigned airworthiness life limit.
- 3.2.9 No pre-existing damage (stress riser) was detected by detailed metallurgical examination of the failed crosstube.
- 3.2.10 The failed crosstube, had a manufacturing abnormality.
- 3.2.11 The failed crosstube wall thickness was not consistent.



- 3.2.12 The failed crosstube was found to have an unusual amount of eccentricity at the point of failure and this was determined to be a contributing cause.
- 3.2.13 The crosstube manufacturer employed ultrasonic inspections after the machining process and put quality controls in place to prevent reoccurrence on all newly manufactured tubes.
- 3.2.14 The failed crosstube found to have four cracks, but they were not detected, due to their position and paint cover during prior inspections.
- 3.2.15 Following Fluorescent Penetrant Inspection of the failed section with cracks, it was revealed that there were more cracks.
- 3.2.16 There were reports of other similar crosstube fractures worldwide.
- 3.2.17 The investigation found in total five events including the two failed crosstubes in the UAE.
- 3.2.18 The UAE regulations have provisions for aerodromes.
- 3.2.19 The UAE GCAA has published a notice for proposed amendment regarding the offshore helideck.
- 3.2.20 The UAE GCAA has not currently published regulations for the offshore helidecks' surface coating material.
- 3.2.21 Following the two UAE occurrences the landing gear manufacturer released a service bulletin to its client base with a life limit of 10,000 landings and added an LPI after 7500 landings was established, on crosstubes.
- 3.2.22 Following the failed crosstubes occurrences the landing gear manufacturer has initiated crosstube design improvement.
- 3.2.23 The State of Design⁵⁰ and the State of Manufacture⁵¹ issued Airworthiness Directives, which added a life limit of 10,000 landings to the crosstube and removed from service any crosstubes with more than 10,000 accumulated landings.
- 3.2.24 In addition to the Ads' 10,000 landings life limitation, the helicopter Operator imposed a 2500 landings LPI, which was significantly lower than the manufacturer's 7500 landings PLI limit.

⁵¹ The State having jurisdiction over the organization responsible for the type design.

⁵² The State having jurisdiction over the organization responsible for the final assembly of the aircraft.



3.2.25 Following the new life limit of 10,000 landing, there were no new crosstube failures.

3.3 Cause

The cause of the occurrence was the fracture of the undercarriage aft crosstube due the metallurgical fatigue.

3.4 Contributing factors

Contributing factors for the fracture of the aft crosstube were:

- 3.4.1** the manufacturing abnormality which created a differential crosstube wall thickness,
- 3.4.2** the repeated stress due to cyclic loading on the crosstube,
- 3.4.3** the metallurgical fatigue, which was not discovered, prior to failure, by the existing inspections,
- 3.4.4** the existing, at the time of the occurrence, inspection intervals,
- 3.4.5** the surface on which helicopters land.

4. SAFETY RECOMMENDATIONS

4.1 FINAL REPORT SAFETY RECOMMENDATIONS

The Safety Recommendations listed in this Report are proposed according to paragraph 6.8 of Annex 13 to the Convention on International Civil Aviation, and are based on the Findings listed in Section 3 of this Report. The GCAA expects that all safety issues identified by the Investigation in the Findings are addressed by the appropriate States and organizations.

4.1 Safety Actions Taken

Below is a summary of the safety actions taken by the landing gear manufacturer, the Transport Canada Civil Aviation and the aircraft Operator, because of this occurrence.

4.1.1 The Landing Gear Manufacturer

- I. The fatigue analysis that was performed on the D412-664-203 crosstube was revised.
- II. A life limit of 10,000 landings and added an LPI after 7500 landings was established.



- III. This information was released to the customer base via Service Bulletin SB 11-2
- IV. A revision to the ICA followed to include the life limit and the LPI inspection
- V. Coordination was performed so TCCA to issue an Airworthiness Directive
- VI. Development of an improved 412 aft crosstube manufactured from a more fatigue resistant material

4.1.2 Transport Canada Civil Aviation

Transport Canada issued an Airworthiness Directive for the crosstube (AD-CF-2012-14R1), which adds a life limit of 10,000 landings to the crosstube and removes from service any crosstubes with more than 10,000 accumulated landings.

4.1.3 Federal Aviation Administration

The USA Federal Aviation Administration issued an Airworthiness Directive for the crosstube (Docket No. FAA-2013-0145; Directorate Identifier 2012-SW-059-AD; Amendment 39-17554; AD 2013-16-16), which adds a life limit of 10,000 landings to the crosstube and removes from service any crosstubes with more than 10,000 accumulated landings.

4.1.4 The Aircraft Operator

Following the two events the Operator proactively imposed a 2500 landings LPI, which was significantly lower than the manufacturer's 7500 landing PLI limit. The 10,000 landings life limits remained.

4.2 Safety Recommendations

To the State of the Operator:

SR022/2014 The GCAA/Aerodromes should ensure that the current regulations accommodate the need for non-slip material on offshore helidecks' surface where UAE registered helicopters are operating.

SR023/2014 The GCAA/Aerodromes should ensure that all helidecks, where UAE registered helicopters operate and all offshore helidecks in the UAE, meet the same safety surface standards.

END