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Defect Analysis on Boeing 737-400 Skin Panel Rivet Row Aft Ward Fuselage

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Abstract: Non-destructive testing defect analysis has been long used as a lead to safeguard against an incident due to damage limitation. This is especially vital for the aging aircraft to protection against possible issue respectively. Defect analysis using non-destructive testing mean to be conducted on Boeing 737-400 skin panel rivet row aft ward fuselage. Project were conducted at University Kuala Lumpur Malaysian Institute of Aviation Technology (UNIKL MIAT). The purpose of this project is to determine percentage of material loss in between rivet row of Boeing 737-400 skin panel from BS 747 to BS 967, crack inspection on Boeing 737-400 skin panel rivet row aft ward fuselage and to analyses collected data for usability of rivet panel on Boeing from 737-400 BS 747 to BS 967. The result for the inspection carried out on the fuselage BS 747 to BS 967 shows that the subsurface has exceed 30% of material loss, crack has exceeded 0.2 inch and conductivity are not within limitation as per the Aerospace Material Specification AMS2658C. Such data for future references about its reference point data on the current state and condition of the aircraft were created and the aircraft require further investigation and possible repair need to be carried out to ensure safety for students and lecturer doing practical on the aircraft.

Keywords: Non-destructive Testing (NDT), defect analysis, skin panel rivet, Boeing 737-400

I. INTRODUCTION

In Non-Destructive Test (NDT) philological the word “defect” is fittingly applied only to a state which will affect with the safe or satisfactory service of part in question. NDT is one of inspection technique. There are many types of NDT techniques such as Eddy Current Testing (ECT), Penetrate Testing (PT) Magnetic Testing (MT) Ultrasonic Testing (UT) and Radiographic Testing (RT) [1]. One of the conventional electromagnetic methods used for the inspection of conductive materials such as copper, aluminum or steel is eddy current nondestructive testing. All these testing did not damage to the materials or specimens. This research is focusing on ECT.

ECT is one of various electromagnetic testing methods used in NDT making use of induction to sense and characterize surface and sub-surface defects in conductive materials. In-service defects could ascend due to components operating under extreme conditions, poor preventive maintenance programme of the components and systems or due to some outside cause like foreign object damage (FOD).

The success of NDT method depends upon the facts of several type of engineering material come across, the procedure by which the component is made of and the possible stages at which the flaw may creep-in [2].

Corrosion

Aircraft is somehow being a metallic object and inherently disposed to corrosion. Lots of time spent painting an aircraft to aid delay corrosion, but unavoidably, nature will prevail. Generally, the growth of corrosion will be subject to on how old the aircraft is, what type of environment it is based in, whether it is hangered, and how often maintenance is being carried out [3]. This subject report discusses the analysis of an aging aircraft (Boeing 737-400) on its corrosion, conductivity and crack. Boeing 737-400 at UNIKL MIAT does not have database for previous defect history. It is park at the apron for a very long time which is exposed to high temperature, humidity and supposedly it should be covered from being exposed towards weather. Hence it is essential to create such data for future references about its reference point data on the current state and condition of the aircraft. A task analysis of inspection by the author was carried out as part of the constant measure against crack, conductivity and corrosion of the aircraft.

Objectives

- To determine percentage of material loss in between rivet row of Boeing 737-400 skin panel BS 747 to BS 967.
- To conduct crack inspection on Boeing 737-400 skin panel rivet row aft ward fuselage.
- Analyses collected data for usability of rivet panel on Boeing 737-400 BS 747 to BS 967.

Research Goals

Inspection method used to determine the percentage of material loss in between rivet row is by using the eddy current testing. The data is recorded if there is defect on between the rivet row along the Boeing 737-400 skin panel BS 747 to BS 967. As the results obtained, the collected data is analyzed for the usability of the rivet row on the aircraft and clarify the safeties of personnel to get inside the aircraft to do practical session.

Scope and Limitation

Scope for my final year project is limited to selected aircraft which is Boeing 737-400 BS 747 to BS 967 skin panel rivet row aft ward fuselage by using eddy current testing 90° probe and donut probe.

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Other application might not produce the result intended due to limited use of equipment and adequate instrument and samples.

Summary

As a summary NDT technique that had been done at modern aircraft should be also tested on aging aircraft as to ensure the serviceability and airworthiness of the aircraft that follows the standard regulation.

II. LITERATURE REVIEW

Rivet Row Defect Analysis

According to Moreira et. al. (2009) one of the main problems of aeronautical structures is damage due to fatigue, a phenomenon accentuated in areas of stress concentration, as for example the connections of fuselage panels, often done by riveting. Several geometric configurations are used to study riveted joints [4].

Classification of Defect That Often Occur on Aircraft

Findlay & Harrison (2002) stated that in general, failures occur when a component or structure is no longer able to withstand the stresses imposed on it during operation [5]. Commonly, failures are associated with stress concentrations, which can occur for several reasons including:

- Design errors such as the presence of holes, notches, and tight fillet radii;
- The structure of the substantial may contain voids, inclusions.
- Corrosive attack of the substantial like pitting, can also generate a local stress concentration.

Non-Destructive Test (NDT) of Aircrafts

Namkung et. al. (2016) described that the Aloha jet incident of 1988 over the Hawaiian Islands is a textbook example of a corrosion fatigue fracture failure that could have been prevented had reliable and low-cost NDT methods been readily available. In this incident, the canopy of a commercial airliner, which had been damaged by fatigue and corrosion, fractured and blew off during flight. The incident provided a clear motivation in the USA for a focused development effort in the 1990s. As a result, several NDT methods designed specifically for the detection of flaws in thin metallic multilayers have been developed in the USA and elsewhere [6].

III. METHODOLOGY

Introduction

According to Scheer & Frische (2005), Figure 1 shows the typical joints on aircraft body, In the riveted connections fatigue cracks may occur from the applied forces. For this reason, many of the riveted connections must be inspected in certain intervals. The eddy current inspection of the riveted joints using a sliding probe following the inspection procedures written in the Nondestructive Testing Manuals (NDTM) is a commonly used method. The multifrequency eddy current technique provides more information from the inspected structure. Therefore, we have set out to develop a new system that not only applies multifrequency ECT to the inspection of rivet rows, but also aims to set new standards on analysis and documentation.

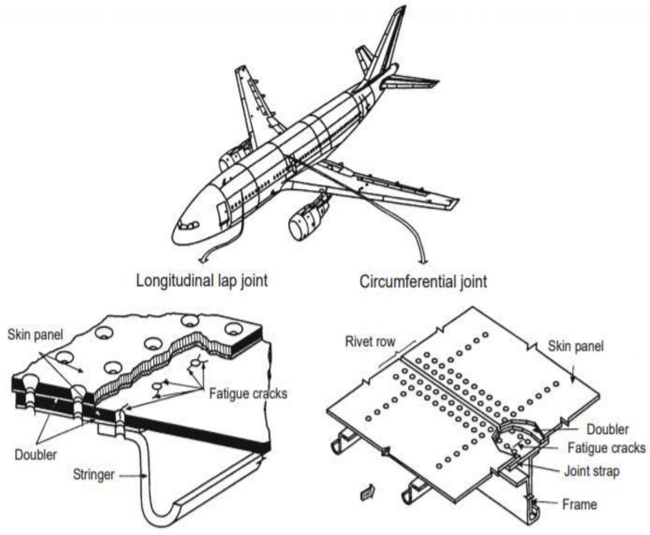


Fig. 1 Lap joints or butt joints [7]

Corrosion Inspection on Rivet Row panel B737

All three procedures require two tools: Eddy current Olympus display and Eddy cable; the different ones would be the probes used and the referred documentations. All the tools and reference documentations used during this entire research process have been are still being used for training aircraft maintenance technicians at an Approved Training Organization by Civil Aviation Authority Malaysia [8]

Fig. 2 Eddy current Olympus display

Fig. 3 Eddy current Cable (UniKL MIAT)

Tools

Fig. 4 Flat-surface probe

Equipment

To do this procedure, eddy current instrument have a continuous frequency selection, and which get the necessary results of this procedure must be used. These instruments were used:

- MTZ 10B Zetec
- MTZ 10A Zetec

Flat surface probes must be used. Select probes which operate at the necessary frequency. Usually probes with small active diameters are better because they find small areas of corrosion more accurately. These probes are used:

- SPO 1598
- SNG 375-3L
- SPO 565A

Crack Inspection on Rivet Panel

Tools

Fig. 5 90° probe

Boeing Service Bulletin (SB) as reference document

This eddy current procedure to help find cracks that extend from a fastener location in fuselage skins where the fastener head cannot be seen because of decals.

Conductivity Test on B737

Tools

Fig. 6 Donut probe

American Society for Testing and Material (ASTM) as reference document

ASTM D 2624 – Test Methods for Electrical Conductivity of Aviation and Distillate Fuels.

IV. ANALYSIS

Introduction

Boeing 737-400 at UNIKL MIAT does not have a database for earlier defect through out of service years. It is parked at the apron for a very long time which was exposed to high temperature and humidity. Supposedly it should be covered from being exposed to outside. Hence it is essential to create such data for future references about its reference point data on the current state and condition of the aircraft. A task analysis of inspection by the author was carried out as part of the constant measure against crack, conductivity and corrosion of the aircraft.

The objective of the research was to determine percentage of material loss in between rivet row of Boeing 737-400 skin panel BS 747 to BS 967, to conduct crack inspection on Boeing 737-400 skin panel rivet row aft ward fuselage and to analyses collected data for usability of rivet panel on Boeing 737-400 BS 747 to BS 967.

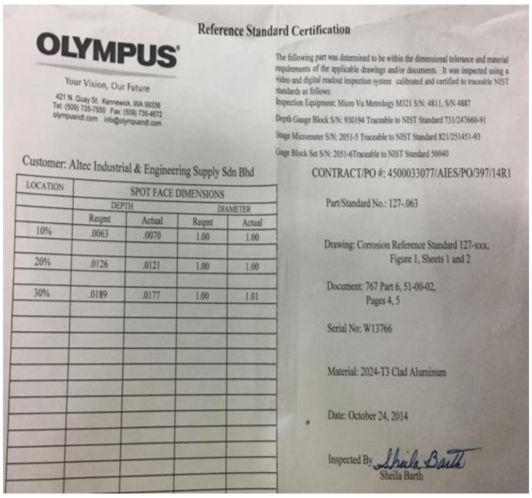
Inspection Zone

The body station at the Boeing 737 from BS 747 to BS 967 has been divided to 4 Zone which is Zone A, Zone B, Zone C and Zone D. The Zone was divided to 4 section with 10 rivet panel on each Zone. This Zone was developed for research purpose as evidence showed in Figure 7.

Fig. 7 Inspection Zones

Defect of Rivet Row on B737-400 Skin Panel BS 747 to BS 967

Inspection for material loss has been conducted on rivet row of Boeing 737-400 skin panel BS 747 to BS 967 calibrated via Olympus Corrosion Standard Reference (10%, 20%, 30%) in the aluminum outer skin at the faying surface of structures with two layers. Standard reference along with the certification is shown as Figure 8.



Reference Standard Certification

OLYMPUS

Your Vision, Our Future

421 N. Quay St. Kennewick, WA 99336
Tel: (509) 735-7550 Fax: (509) 735-4672
olympusndt.com info@olympusndt.com

The following part was determined to be within the dimensional tolerance and material requirements of the applicable drawings and/or documents. It was inspected using a video and digital readout inspection system calibrated and certified to traceable NIST standards as follows:
Inspection Equipment: Micro Vu Metrology M321 S/N: 4811, S/N 4887
Depth Gauge Block S/N: 930194 Traceable to NIST Standard 731/247660-91
Stage Micrometer S/N: 2051-5 Traceable to NIST Standard 821/251451-93
Gage Block Set S/N: 2051-6Traceable to NIST Standard 50040

Customer: Altec Industrial & Engineering Supply Sdn Bhd

CONTRACT/PO #: 4500033077/AIES/PO/397/14R1

LOCATION	SPOT FACE DIMENSIONS			
	DEPTH		DIAMETER	
	Reqmt	Actual	Reqmt	Actual
10%	.0063	.0070	1.00	1.00
20%	.0126	.0121	1.00	1.00
30%	.0189	.0177	1.00	1.01

Part/Standard No.: 127-.063

Drawing: Corrosion Reference Standard 127-xxx,
Figure 1, Sheets 1 and 2

Document: 767 Part 6, 51-00-02,
Pages 4, 5

Serial No: W13766

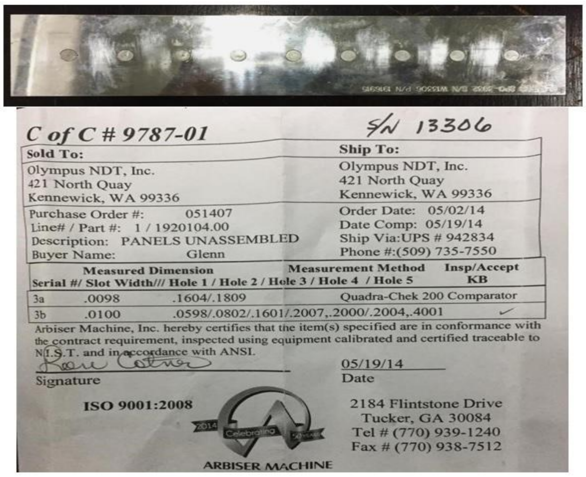
Material: 2024-T3 Clad Aluminum

Date: October 24, 2014

Inspected By Sheila Barth
Sheila Barth

Fig. 8 Olympus material loss Standard Reference Certification

The inspection for crack on the rivet row skin panel from Zone A to Zone D calibrated via Olympus Standard Reference (0.0598, 0.1601", 0.2004"). Standard reference along with the certification is shown as Figure 9.



C of C # 9787-01

S/N 13306

Sold To:	Ship To:
Olympus NDT, Inc. 421 North Quay Kennewick, WA 99336	Olympus NDT, Inc. 421 North Quay Kennewick, WA 99336
Purchase Order #: 051407 Line# / Part #: 1 / 1920104.00 Description: PANELS UNASSEMBLED Buyer Name: Glenn	Order Date: 05/02/14 Date Comp: 05/19/14 Ship Via:UPS # 942834 Phone #:(509) 735-7550

Measured Dimension Serial #/ Slot Width/// Hole 1 / Hole 2 / Hole 3 / Hole 4 / Hole 5			Measurement Method	Insp/Accept KB
3a	.0098	.1604/.1809	Quadra-Chek 200 Comparator	
3b	.0100	.0598/.0802/.1601/.2007,.2000/.2004,.4001		✓

Arbiser Machine, Inc. hereby certifies that the item(s) specified are in conformance with the contract requirement, inspected using equipment calibrated and certified traceable to N.I.S.T. and in accordance with ANSI.

Signature

05/19/14
Date

ISO 9001:2008

ARBISER MACHINE

2184 Flintstone Drive
Tucker, GA 30084
Tel # (770) 939-1240
Fax # (770) 938-7512

Fig. 9 Olympus crack Standard Reference Certification

For the analyses data, conductivity test is required to know the usability of the rivet panel. The inspection for conductivity on the rivet row skin panel Zone A to Zone D calibrated via Olympus Standard Reference using aluminum alloy 7075-T6 32% and aluminum alloy 7075-T0 45%. Standard reference is shown as Figure 10.

Fig. 10 Olympus conductivity Standard Reference

All the results for material loss, crack and conductivity test on Zone A and Zone B is tabulated as evidence on Table 1 and for Zone C and Zone D is on Table 2.

Table. 1 Results of Defect in Zone A and Zone B

Zone	Rivet row from BS 747 to BS 967	Material Loss (%)	Crack (inch)	Conductivity (%)
A	1	NIL	0.0598	41.04
	2	>10	0.0598	49.18
	3	>10	NIL	47.66
	4	NIL	NIL	41.27
	5	>20	0.2004	39.52
	6	>20	NIL	38.41
	7	NIL	0.2004	49.18
	8	>30	0.0598	47.82
	9	>20	0.1601	41.87
	10	NIL	NIL	38.46
B	1	NIL	0.0598	38.38
	2	NIL	0.1601	38.41
	3	>20	0.1601	38.49
	4	>30	NIL	38.35
	5	>10	NIL	41.04
	6	>10	NIL	38.46
	7	>30	0.1601	41.27
	8	NIL	0.0598	49.18
	9	NIL	NIL	47.66
	10	>30	0.0598	38.84

Table. 9 Results of defect in Zone C and Zone D

Zone	Rivet row from BS 747 to BS 967	Material Loss (%)	Crack (inch)	Conductivity (%)
C	1	>10	0.1601	41.04
	2	>10	NIL	38.84
	3	>20	0.1601	39.77
	4	NIL	0.0598	41.27
	5	>20	0.2004	39.52
	6	>10	NIL	47.66
	7	NIL	0.2004	41.27
	8	NIL	NIL	49.18
	9	>30	0.2004	41.87
	10	>30	NIL	38.46
D	1	NIL	0.2004	38.38
	2	>20	0.1601	38.41
	3	>30	NIL	38.49
	4	>30	0.2004	38.35
	5	>10	NIL	41.27
	6	NIL	0.1601	38.46
	7	NIL	0.0598	41.27
	8	>10	NIL	49.18
	9	>30	0.1601	47.66
	10	>20	0.0598	38.84

V. DISCUSSIONS

Material Loss

The result for the material loss test is gain and the data was referred to the Olympus Standard reference. The line if it cross to one grid is considered that the sub surface has 10% of material loss. This is shown in Figure 11. Line that cross on three grids is considered the sub surface has 20% material loss as shown in Figure 12. For line that across on four grids is considered that the sub surface has 30% of material loss as evidence in Figure 13.


11/16/2013 08:00AM
FREQ 1
FREQ 3.0KHz
ANGLE 85.0deg
GAIN
H GAIN 75.0dB
V GAIN 75.0dB

Fig. 11 10% of material loss

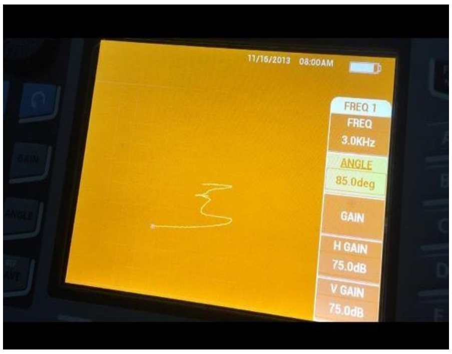

11/16/2013 08:00AM
FREQ 1
FREQ 3.0KHz
ANGLE 85.0deg
GAIN
H GAIN 75.0dB
V GAIN 75.0dB

Fig. 12 20% of material loss


11/16/2013 08:00AM
FREQ 1
FREQ 3.0KHz
ANGLE 85.0deg
GAIN
H GAIN 75.0dB
V GAIN 75.0dB

Fig. 13 30% of material loss

Crack

The result for crack test is gain and the data was referred to the Olympus Standard reference. The line if it cross on one grid is considered that the sub surface has 0.0598-inch crack. This is shown as Figure 14. Line that cross on three grids is considered the sub surface has 0.1601 inch as shown in Figure 15. For line that across on four grids or more is considered that the sub surface has 0.2004 inch of crack or more as evidence in Figure 16.


11/16/2013 07:51AM
FREQ 1
FREQ 3.0KHz
ANGLE 85.0deg
GAIN
H GAIN 75.0dB
V GAIN

Fig. 14 0.0598 inch of crack


FREQ 1
FREQ 3.0KHz
ANGLE 85.0deg
GAIN
H GAIN 75.0dB
V GAIN 75.0dB

Fig. 15 0.1601 inch of crack

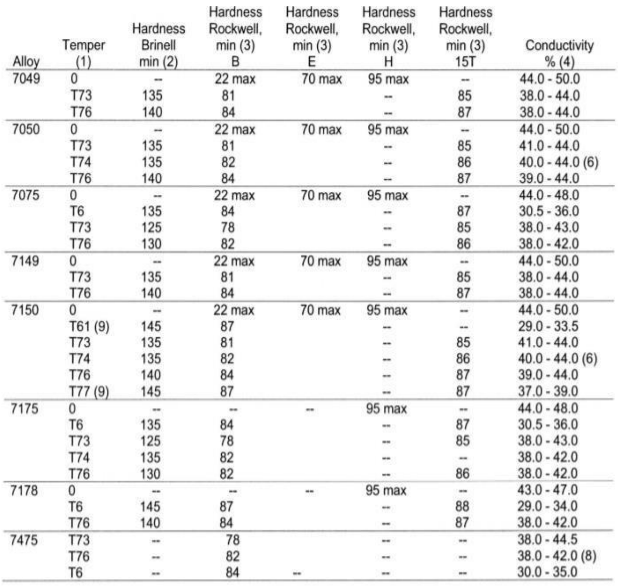
11/16/2013 07:51AM
FREQ 1
FREQ 3.0KHz
ANGLE 85.0deg
GAIN
H GAIN 75.0dB
V GAIN

Fig.16 0.2004 inch of crack

Conductivity

The result for conductivity test is gain and the data was referred to the Olympus Standard reference using alloy 7075 Temper (0). The percentage shows the conductivity gain at the subsurface that in contact with the probe. The conductivity percentage is then converted to hardness as per Figure 18. Hardness testing determines the material's resistance to plastic (permanent) deformation and brittleness. This correlates directly to the strength and wear resistance of a part. If the value is below the limitation the subsurface is affected by deformation whereas if the value exceeds the limitation it is affected by brittleness. Figure 17 shows the comparison of the results for the conductivity test at the fuselage BS 747 to BS 967.

Fig. 17 Comparisons of Conductivity Test Results



Alloy	Temper (1)	Hardness Brinell min (2)	Hardness Rockwell, min (3) B	Hardness Rockwell, min (3) E	Hardness Rockwell, min (3) H	Hardness Rockwell, min (3) 15T	Conductivity % (4)
7049	0	--	22 max	70 max	95 max	--	44.0 - 50.0
	T73	135	81		--	85	38.0 - 44.0
	T76	140	84		--	87	38.0 - 44.0
7050	0	--	22 max	70 max	95 max	--	44.0 - 50.0
	T73	135	81		--	85	41.0 - 44.0
	T74	135	82		--	86	40.0 - 44.0 (6)
	T76	140	84		--	87	39.0 - 44.0
7075	0	--	22 max	70 max	95 max	--	44.0 - 48.0
	T6	135	84		--	87	30.5 - 36.0
	T73	125	78		--	85	38.0 - 43.0
	T76	130	82		--	86	38.0 - 42.0
7149	0	--	22 max	70 max	95 max	--	44.0 - 50.0
	T73	135	81		--	85	38.0 - 44.0
	T76	140	84		--	87	38.0 - 44.0
7150	0	--	22 max	70 max	95 max	--	44.0 - 50.0
	T61 (9)	145	87		--	--	29.0 - 33.5
	T73	135	81		--	85	41.0 - 44.0
	T74	135	82		--	86	40.0 - 44.0 (6)
	T76	140	84		--	87	39.0 - 44.0
	T77 (9)	145	87		--	87	37.0 - 39.0
7175	0	--	--	--	95 max	--	44.0 - 48.0
	T6	135	84		--	87	30.5 - 36.0
	T73	125	78		--	85	38.0 - 43.0
	T74	135	82		--	--	38.0 - 42.0
	T76	130	82		--	86	38.0 - 42.0
7178	0	--	--	--	95 max	--	43.0 - 47.0
	T6	145	87		--	88	29.0 - 34.0
	T76	140	84		--	87	38.0 - 42.0
7475	T73	--	78		--	--	38.0 - 44.5
	T76	--	82		--	--	38.0 - 42.0 (8)
	T6	--	84	--	--	--	30.0 - 35.0

Fig. 18 Aluminum Alloy Hardness and Conductivity Acceptance Value [9]

Pareto Chart for Material Loss

The graph from Figure 19 below shows that 80% of the material loss comes from Zone B, Zone D and Zone A. These Zones are the most affected area from material loss due to exposal to the outside high temperature and humidity. Thus, these area needs further investigation and possible repair.

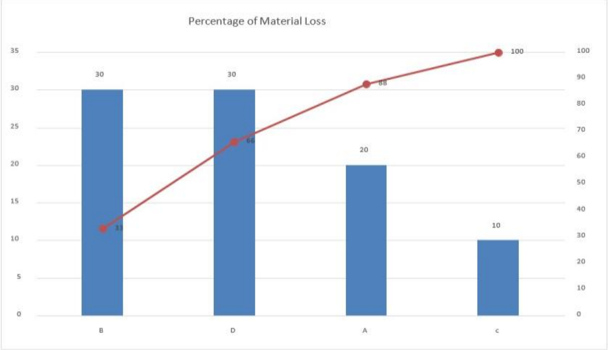


Fig. 19 Percentage of Material Loss Analysis

Pareto Chart for Crack

The graph from Figure 20 below shows that 80% of the crack comes from Zone c, Zone B and Zone D. These Zones are the most affected area from cracks base on the inspection carried out. Hence, it is essential for further investigation and possible repair to avoid these fatigue crack elongates and danger another area of the fuselage.

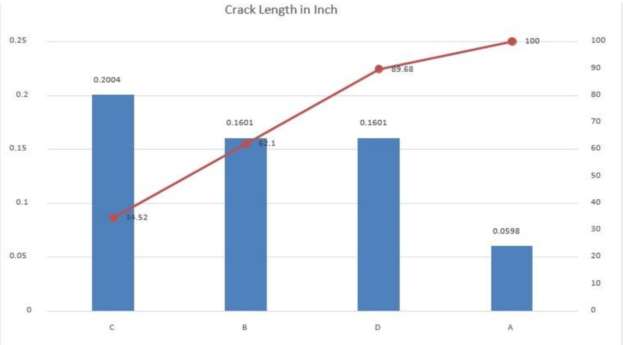


Fig. 20 Crack Analysis

Pareto Chart for Conductivity

The graph from Figure 21 below shows that 80% of the subsurface that expose deformation and brittleness comes from Zone D, Zone A and Zone C. These Zones are the most affected area from deformation and brittleness as the Zones are not within the limitation range for alloy 7075 Temper (0) which is from 44% to 48%. If the value is below the limitation the subsurface is affected by deformation whereas if the value exceeds the limitation it is affected by brittleness.

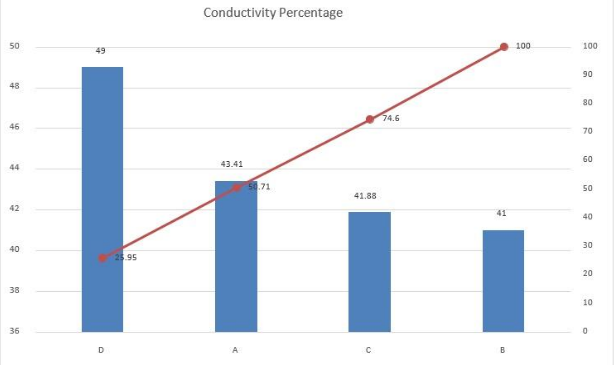


Fig. 21 Conductivity Test Analysis

VI. CONCLUSION

Summary

The outcome for this thesis is that the aging aircraft of Boeing 737-400 specify in BS 747 to BS 967 at UniKL MIAT Apron is full of fatigue defects and it may cause problem if personnel get themselves inside the aircraft. The only inspection area that has been covered is on the fuselage BS 747 to BS 967, whereas the other part is not covered, the danger may come from the other part and causing the whole aircraft is not safe because the characteristics of crack is that it can elongate and damage another undamaged part.

Furthermore, a logbook is important to show the database of the aircraft for future references about its reference point data on the current state of the aircraft.

As this project has completed all the objectives have been achieved with the result and data. First objective is to determine percentage of material loss in between rivet row of Boeing 737-400 skin panel BS 747 to BS 967 and the test result as evidence in table 8 and table 9 show that material loss is ranging from 10% and exceeding 30% which shows that the part is not safe and need further investigation and possible repair.

Second objective is to conduct crack inspection on Boeing 737-400 skin panel rivet row aft ward fuselage and the results say that the test result as prove in Pareto Chart for Crack (4.4.3) shows that Zone C, Zone B and Zone D need to be repaired as crack from that area can elongate and endanger undamaged area to crack.

Lastly, the objective is to analyses collected data for usability of rivet panel on Boeing 737-400 BS 747 to BS 967 and the result says that the inspection carried out on the fuselage BS 747 to BS 967 shows that the subsurface has exceed 30% of material loss, crack has exceeded 0.2 inch and conductivity are not within limitation as per the Aerospace Material Specification AMS2658C. The aircraft require further investigation and possible repair need to be done.

Recommendation

It is very important to conclude that eddy current give good results on detecting defects on fuselage but there is slightly difference on their time of result. I would recommend different probes such as sliding probe for faster result but when comes to a critical area such as small area it is recommended to use pencil probe as this experiment had use. It is recommended for finite element analyzing technique to be employed in future research as well.

Future Work

For future project, another method of non-destructive testing method such as ultrasonic testing and radiography testing for detection of defects and for the strength determination shall be done to detect more details about defects on certain surface or subsurface. Continuation of doing eddy current on detecting flaws on the fuselage covering more body station and Zone to ensure the safeties of the aircraft.

In addition, more alternative and innovative testing methods need to be experimented and researched on for the significant development of aviation related studies. These future researches are imperative for both technical (such as aircraft repair parts [10-15] and processes [16-17], electrical and electronics studies [18-22], and human safety awareness technology [23-27]) and non-technical domains (such as business opportunities [28], sociology [29], and management [30]) alike.

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