Technical, Safety and Economical Aspects of Considering Repair to Aircraft Structures

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Abstract: The design of repair for airframe structural damage requires a working knowledge of the material properties and it's applications, the nature of structural loading and deformation and principles of joint design. The structures engineers who have those knowledge will be able to rectify the damaged aircraft structures with adequate and timely repairs. The airplane Manufacturer Structures Engineer utilises recognised engineering principles, approved material allowable and state of the art fatigue design technology to produce an airplane capable of assuring a high level of fleet reliability while the Airline or MRO Structures engineer is limited by the parameters of the local structure in the damaged area and must design repairs to restore the structural integrity with limited resources under stringent maintenance deadlines and often during unscheduled downtime. Therefore, structurally safe and economical operations of civil transport airplanes are a highly complex team effort which requires early and on-going operation between the Airline and Manufacturer Structures Engineers. This paper outlines the demanding tasks experienced by the Airline Structures Engineer and provides an overview the challenging tasks when considering repair to aircraft structures in the aspects of technical, safety and cost effectiveness.

1.0 INTRODUCTION

This study outlines the factors that need to be considered prior to repair to the aircraft structures. The study will focus on the technical, safety and economical aspects of considering repair to aircraft structures. The discussion will be more confined towards Aircraft Structures Engineer working either with Airlines or repair organization such as Maintenance, Repair and Overhaul Organization (MRO). Repair is required when the aircraft structures were found damaged due to several reasons such as impact, fatigue failure, overheat, incorrect repair procedure, misaligned of attachment holes due to preloading conditions etc. In addition, the structures and stress engineer must also know the safety factor or margin of safety of the affected areas. The design of repair to aircraft structures requires a working knowledge of the material properties and it's applications, the

nature of structural loading and deformation and principles of joint design. In addition, the knowledge of the safety factor or margin of safety of the affected areas is also important. As an engineer, the economical aspect of the repair must also be considered in designing a repair. All these criterias must be seriously considered in order to ensure that the repair is carried-out in accordance with very stringent airworthiness requirements, safe and economical.

Overview of Maintenance Operations

The structural discrepancies are ahead of other type of defects reported by the maintenance personnel either during aircraft operations or various maintenance visits such as A, B, C and D checks. It can be as high as 75% especially during aircraft heavier maintenance checks such as C and D (Heavy Maitenance Visit). Other reported defects such as powerplant, system and even avionics are sometimes structural related in which the Structures Engineer is required to rectify the defects. As such in the case of engineering support, the number of Structures Engineer is the highest if compared to the other disciplines.

As discussed, the airline structures and stress engineers who have the sufficient knowledge of the material properties and it's applications, the nature of structural loading and deformation and principles of joint design is able to rectify the affected aircraft structures with adequate and timely repairs. As the airplane Manufacturer Structures Engineer utilises recognised engineering principles, approved material allowables and state of the art fatigue design technology to produce an airplane capable of assuring a high level of fleet realibility, the Airline or MRO Structures Engineer is limited by the parameters of the local structure in the damaged area and must design repairs to restore the structures with limited resources under stringent maintenance deadlines and often during unscheduled downtime.

Designing a repair scheme on the aircraft is not an easy task. A lot of factors need to be considered such as accessibility, work place condition, preloading consideration etc. The area of repair can be divided into accessible and inacessible areas. If the damaged area is accessible at both sides then the repair parts installation process will become easier and will have more options than the damaged area which is limited to one side only. For example, solid fasteners can be installed instead of blind fasteners in the accessible area thus providing secured and stronger installation. During aircraft manufacturing, the condition of inaccessibility is minimal as parts installation can be well planned. For example, during the process of repair, the installation of solid fasteners in the upper panel of horizontal stabilizer is not possible due to nil access to the inner compartment side or area of the affected stabilizer. Such condition will not happen during manufacturing as the installation of the lower panel of the stabilizer can be deferred at later stage in order to allow the installation of upper panel ahead of lower panel. This process arrangement will accommodate the installation of solid fasteners due to availability of access at both sides. As such, it is not easy to properly plan a structure repair as a lot of obstacles are expected to be faced by the Airline Structures Engineer throughout the process of designing an optimum repair.

2.0 TECHNICAL CONSIDERATIONS

Introducing a structural repair to an aircraft component affects its original configuration in many ways. These actions that can be considered modification to the aircraft original design typically increase aircraft weight by a small percentage and alter the aerodynamics of the aircraft particularly if the repair is external patch. Structural repairs also change the static strength and durability of the structure.

When defects are discovered during inspections, the structures or components must be either repaired or replaced. Often the inspections are carried-out during aircraft 'A' check and during aircraft hangar visits. However the defects can also be found during shorter transit or stayover check normally due to impact. In most instances, it is not economically feasible to replace the entire components such as wing or even wing to body fairing. Therefore the repair is the prudent decision.

The standard of damage/repair procedures can be explained as illustrated in Figure 1. When the damage is reported by normally the License Aircraft Maintenance Engineer (LAME) or Non-Destructive Test (NDT) Personnel, the structures repairer or technician must assess the damage as per guidelines given in the Structural Repair Manual (SRM) or equivalent standard manuals. If the damage is within the repairable limits, the technician could proceed of repairing the repair as recommended by the standard manuals. However if the damage is beyond the repairable limits, the technician will normally refer the case to Airline Structures Engineer. There are cases where the repairer will also refer to Stuctures Engineer in order to obtain approval for temporary repair or if the recommended repair outlined in the manual requires some adjustments or amendments. There are also cases where the repair information or sometimes the affected material identification is not available in the manuals. Therefore the structures engineer must be ready to face any type of discrepancies or insufficient information in the process of establishing the acceptable repair.

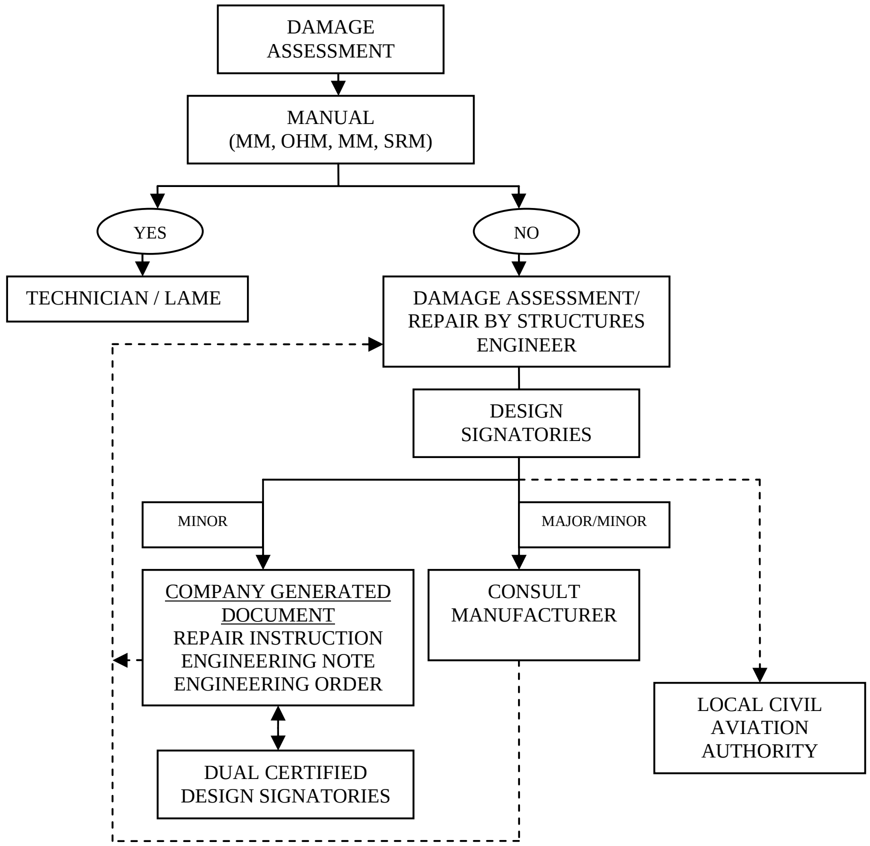

Figure 1: Standard Operating Procedure for Assessing Damage and Establishing Repair

In most cases, there are several categories of repairs that can be used on the damaged structures or components as illustrated in Figure 2. In selecting which repair is best suited for a particular type of damage, the engineer must take into account on several design considerations and cost-effectiveness.

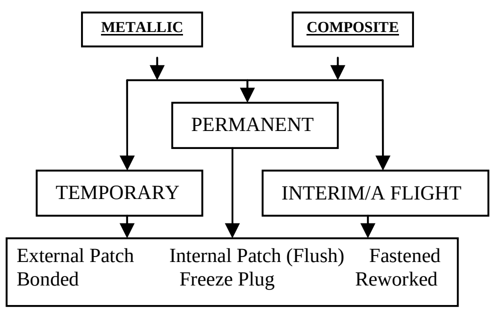

Figure 2: Types of Repair

Preferably the selected repair must have advantages which outweight the disadvantages. Besides these considerations, the final performance requirements for example aerodynamic smoothness must also be considered. The followings are the design considerations that need to be measured prior to selection of repair: -

2.1 Design Life

The type of repair to be considered will depend on the materials, tools, amount of time available, accessibility to the damaged area and maintenance level. There are two categories of repair, permanent and temporary.

A permanent repair is one that restores the strength of the repaired structure equal to or greater than its original strength. It must also satisfy aerodynamic, thermal, durability, inspection and interchangeability requirements. By meeting these requirements, the repair will ensure the design capabilities of the aircraft or in other mean, it should have the ability to perform effetively throughout the design life.

The temporary repair restores the load carrying ability of the structure however the durability, material compatibility, aerodynamic smoothness, instrumental non-destructive inspection if required and physical appearance can be compromised until a permanent repair is accomplished. This repair should be replaced by a permanent type as soon as possible in order for the aircraft to be restored to its normal condition. The post temporary repair may require repetitive inspection at interval defined by structures engineer based on the available approved fatigue data. There is another type of temporary repair which is called one-time flight or interim repair. This category of repair restores a limited load-carrying ability to the damaged structure in order to fly the aircraft to maintenance base for a permanent repair. When this type of repair is accomplished, the flight crews should be informed by annotating the repair information and follow-up instruction in the technical log and possibly placarded to warn them to limit the performance of the aircraft as required.

2.2 Fit and Function

Repairs to aerodynamics surfaces should be as smooth as possible to minimise drag. Therefore flush repair will offer less drag. However external patch or non flush is feasible to speed up repair process as it is easier to accomplish. The repair could have design life limitations as discussed in the earlier topic. The fit-up and clearance to adjacent components must also be maintained after repair.

2.3 Strength

It is always preferable to repair a structure or component to its original design strength. In certain cases like the affected area or component which is non critical or has substantial margins of safety, repair with full strength restoration may not be needed. The combination of temperature extremes and moisture exposure is a critical condition for which the repair must be designed especially if the composite repair is chosen.

It is important to determine the required patch thickness. It has to be based on the affected area stiffness requirements. The bearing and ultimate strength of the repair part must be at least compatible with the original or parent structure. In the case of composite repair, it is extremely important that the patch fibre orientations match those in the parent material or the average stiffness of composite repair part must be equal to the repaired structure.

Joint strength is another important aspect when considering a repair to aircraft structures. A structural joint is defined as a particular segment of structure which functions as a load transfer medium from one or more structural member to adjacent members. The members may be held together with one or more fasteners.[1] Amongst tehnical elements that are required to be considered are type of fastener and it’s strength, fastener’s edge margin and spacing, knife edge condition, hard point elimination etc. In order to eliminate the hard point for example, the edge of doubler is required to be tapered at proven tested ratio. This is to minimise the high level of load carrying by the last row of fastener located at the edge of joint.

Douglas company[2] has listed the factors that can affect the strength of the structural composite repair in the Design Manual. Those factors are:

Design load
Required patch thickness
Layup pattern
Stacking sequence
Adhesive load capacity
Required overlap length
Peel stresses
Surface preparation
Fasteners in laminates

2.4 Durability

All the repairs will be exposed to repeated loads. Generally, the same fatigue and damage tolerance criteria that applies to the basic component will apply to the repair. The fatigue life of the repair must be comparable to the fatigue life of the original affected component or structure. Fatigue failure life of a structural member is usually defined as the time to initiate a crack which would tend to reduce the ultimate strength of the member. As such all factors that can degrade the fatigue life of the structure being repaired such as sharp edges, elongated attachment holes, inadequate number of fasteners or insufficient number of rows and improper installation of fasteners must be eliminated or reduced within the acceptable original stress level.

All composite structure on the exterior of the aircraft are protected against degradation due to ultraviolet ray exposure. For components located in designated lightning strike zones, they are protected by allowing the conduction of lightning strikes using aluminum flame spray, copper mesh and astrostrike. These environmental protection systems must be restored after repair.

2.5 Materials

The choice of repair materials emphasizes the following factors: -

1. High strength to weight ratio
2. Fracture toughness
3. Crack propagation rate
4. Notch sensitivity
5. Stress corrosion resistance
6. Exfoliation corrosion resistance

The repair material must be compatible with the original or parent material. The use of the same type of material is unavoidable as it can prevent dissimilar material corrosion and inadequate strength and/or stiffness. By having the same material as parent material, the repair will not over kill or overweight the affected area. Furthermore the original toughness of the affected area can be restored close to it’s original material characteristic or behaviour.

2.6 Inspectability

The importance of structural inspectability is evident in modern aircraft designs and aging aircraft programmes, which include damage tolerance as an additional technical consideration. Damage tolerant structure will carry anticipated load with damage until detected by inspection and repaired. Damage tolerance involves the determination of crack growth rates within specific structures. Crack growth rates are used to establish thresholds and determine inspection methods and intervals that ensure crack detection prior to structural failure. The principle of damage tolerance is outlined using graphical figure as shown in Figure 3.

Several aspects of a structural repair design must be considered to ensure optimum inspectability. These aspects include doubler geometry, thickness and repair material, fastener’s design, fastener’s material and spacing, sealant application etc. One of the repair objectives is to simplify inspection procedures in order to improve structural safety by allowing for more accurate and through inspection of repair doublers, fasteners and substructures.

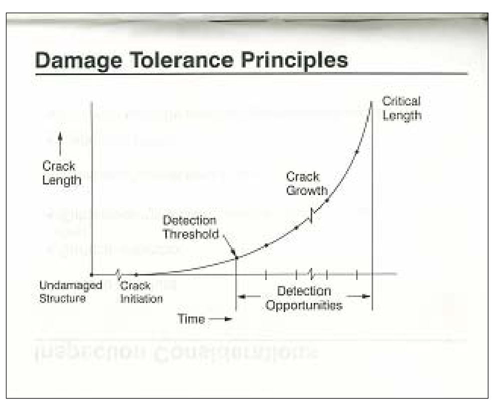

Figure 3: Damage Tolerance Principles

2.7 Weight and Balance

Adding weight to a component as a result of a repair is particularly important when the component is a moveable control surface such as rudder, aileron, elevator etc. These components, although balanced to allow for a small repair, are susceptible to aerodynamic flutter due to changes in mass balance. For repairs over large areas, rebalancing of the part will be necessary.

Structural Classification Awareness

In designing a repair to aircraft structures, the classification of component must be determined prior to selection of repair type. By knowing and understanding the function of the component, the structures engineer will be able to estimate the stress level and operational requirement of the repaired area. This technical awareness and judgement will lead to acceptable repair consideration.

1. Principal Structural Element
   i.e. Stabilizer Bulkhead
2. Flight Control Devices i.e. Aileron
3. Weight Sensitive Devices i.e. Tab
4. Primary: Heavy Loaded Structures
5. Secondary: Light Loaded Structures
6. Fairing: Aerodynamic Loaded Structures
   i.e. Wing and Fuselage
7. Operation Sensitive Structure

Useful Documentations

The following are the documentations or data that can assist the structures engineer in the process of designing an acceptable repair.

1. Structural Repair Manual
2. Overhaul Manual
3. OEM Drawing
4. Maintenance Manual
5. ComponentMaintenance Manual
6. Service Bulletin
7. Airworthiness Directive
8. Illustrated Parts Catalogue
9. Military Handbook 5F or latest version
10. Manufacturer Design Manual etc.

General Repair Procedures

1. Evaluate the damage.
2. Determine material and allowables.
3. Calculate load capability required.
4. Size repair parts in chosen material.
5. Determine type, size and number of fasteners required.
6. Make detailed sketch of complete repair with finishes.
7. Follow applicable standard procedures such as SRM, OHM etc.

3.0 SAFETY

Civil Aviation in particular is a highly regulated industry. Malaysia being a sovereign country has formulated its own air legislation and regulations in line with the International Civil Aviation Organization (ICAO) requirements through an Act of Parliament with the introduction of the Malaysian Civil Aviation Regulations (MCAR).[3]

The repair organization which involves with design activities is governed by British Civil Aviation Regulations (BCAR) A8-8 Group E2 Design Organization. The personnel with or without Design Approval are responsible for generation of design documents within the area of expertise specified in the Design Organization

Exposition (DOE). They must be conversant with all the standard policies in the DOE. The Design Signatories with certain limitation on approvals are highly competent engineers with extensive experience dealing with aircraft repairs and modifications. In order to be qualified as a Design Signatories, they must be first recommended by Head of Engineering and followed by a special Depatment of Civil Aviation, DCA Director due consideration and approval. The stringent adherence to regulations and qualification procedures has in fact produce a safe and airworthy aircraft for passenger comfort.

The last portion of Figure 1, flow-chart, outlines the required procedures in establishing the design document for repair. Once damage is reported, the first thing to do is to gather as much information as possible by refering to Manufacturer Manuals particularly Structural Repair Manual (SRM). This source of approved data is useful for the Structures Engineer to decide the next course of action. If repair is required to be established by the Structures Engineer, several technical or design aspects must be considered. Firstly the status of damage or repair must be determined. The major repairs or modifications are defined as changes that have appreciable effect on the weight and balance or moment change, structural strength, reliability, operational characteristics or other characteristics affecting the airworthiness of the aircraft. If the repair is considered major then the Manufacturer needs to be consulted otherwise the minor repair shall be approved by Design Signatories. In fact, legally, even the manufacturer shall not approve the major repair as this type of repair can only be approved by the competent aviation authorities after due consultation with Aircraft Manufacturer. These processes are subjected to frequent audit by DCA and other competent regulatory authorities to ensure that good judgement is exercised with a full appreciation of current aeronautical practice in design matters in order to ensure that safety is at the highest level.

4.0 ECONOMY

4.1 Design factor

The design of a structural repair has a significant effect on the future maintenance cost associated with inspection for continued airworthiness. Proper consideration of repair materials, fastener types and other repair features can dramatically improve inspectability and ***reduce future maintenance costs*** [4].

Aging airplane, especially, is subjected to extensive and tedious process of Repair Assessment Program as a result of Aloha incident and other related structural incidents. The adequate repair that complies the damage tolerance requirements will eliminate the re-implementation of repair and at the same time will save maintenance cost.

4.2 Time Factor

Loss contribution to operating profit due to one cancellation or one day delay based on aviation industrial average is equivalent to RM 146901.30 (Source: Modification Working Group, Airbus). Therefore time factor is one of the most critical considerations when it comes to the selection of repair type.

Actual Case Studies

Case Study 1

<u>Discrepancy</u>

Severe impact damaged to the LHW leading structures and accessories about 5’ long in span-wise direction. Figures 3 and 4 refer.

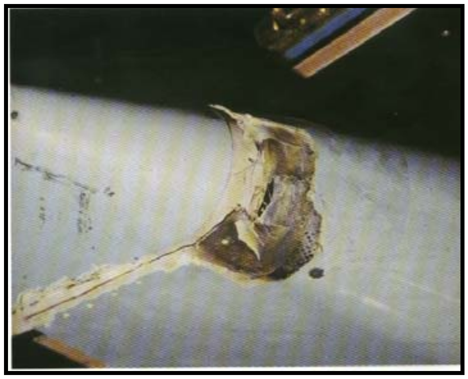

Figure 4: Front View of Damaged Wing
Leading Edge Structures

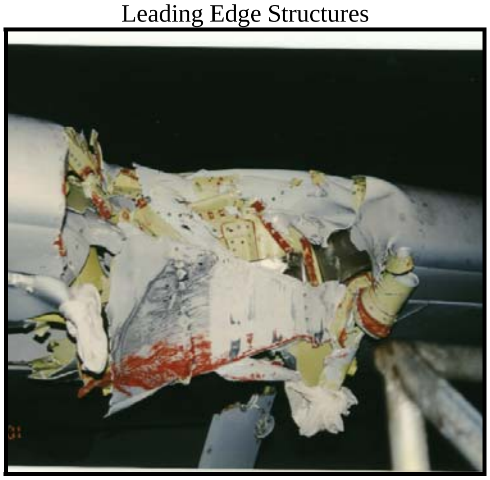

Figure 5: Exploded View of Damaged Wing
Leading Edge Structures

Action

Replaced LE flap, repair LE and associated structures and test. Design document 33EN-57-13656A refers.

Achievement

Repair was targetted to be completed within 5 days. However the damaged was temporarily repaired and restored within 3 days. This 2 days ahead of target contributed a saving of RM 353,802 on operating profit and lease of hangar. Eventually the aircraft returned safely to base for a permanent rectification.

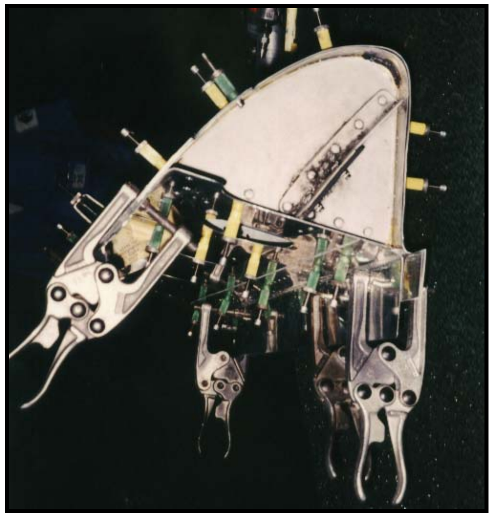

Figure 6: Side View of Repair Parts/Structures

Case Study 2

<u>Discrepancy</u>

No. 4 pylon sustained excessive heat damage to mid-spar chords left and right hands due to adjacent pre-cooler duct coming loose from pre-cooler.

<u>Action</u>

An extensive repair consuming a total of 44 manhour and 16 manhour on design activities respectively. Reference: 70RI-54-7691A

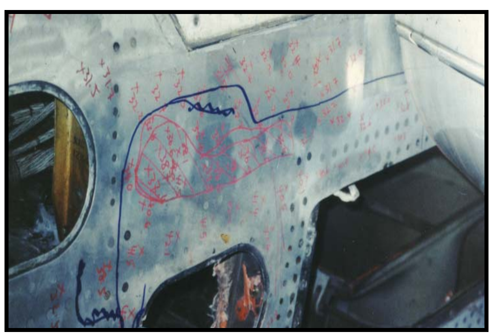

Figure 7: Side View of Pylon Heat Damage
(Conductivity IACS Readings)

<u>Achievement</u>

Cost saving by implementing repair instead of pylon replacement is tabulated as follows: -

Repair on LHS of Pylon,	RM 181420
Repair on RHS of Pylon,	RM 22400
Repair on Shear Web,	RM 4800
Total cost of Repair,	<u>RM 208,620</u>

Pylon Replacement, <u>RM 3724000</u>

Thus, the cost saving is **RM 3,515,380**

5.0 CONCLUSION

In most cases, there are several types of repairs that can be used on a damaged structure. In selecting which repair is best suited for a particular type of damage, the engineer must take into account several technical and design considerations, statically and dynamically. The selected repair must be good enough to restore the original strength of the affected parent structure.

The sophisticated and stringent rules of getting the repair to be approved by the civil aviation authorities are to ensure that the safety of passengers on board is guaranteed.

Repair cost and economical aspects are important factors that need to be seriously considered by Airline Structures Engineer. The cost variables include 'turn around time', repair method, technique and material selection. The main challenge is limited resources under stringent maintenance deadlines and often during unscheduled downtime.

All the above factors require a highly complex team effort in which the main contributors are Airline and Manufacturer Structures Engineers. Whilst the airplane Manufacturer Structures Engineer utilises recognised engineering principles, approved material allowables and state of the art fatigue design technology to produce an airplane capable of assuring a high level of fleet reliability, the Airline Structures Engineer is limited by the parameters of the local structure in the damaged area and accessibility issues which limit their choice of repair.

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BIOGRAPHICAL INFORMATION

Ir. Mohd Dali is the Associate Professor with Universiti Kuala Lumpur Malaysian Institute of Aviation Technology (UniKL MIAT). Upon completion of his B.M.E (Hons) Aeronautics from the University of Technology, Malaysia in 1992, he began his career as a Process Engineer in Seagate – Applied Magnetics (M) Sdn. Bhd. He joined the Malaysia Airline in January 1993 as a Trainee Technical Services Engineer. During this period, he has gone through the training of License Without Type Rating for one and half year. After graduated from the programme, he was responsible as a Structures Engineer for B737 (All Series) and later became a Coordinator and Structures Engineer who was responsible for B747 Fleet Operations including the first in-house Heavy Maintenance Overhaul/Visit Project. He was delegated as a Design Approval Holder for Category II in 1997 and Category I (the highest approval signatories) in 2000 by Department of Civil Aviation, Malaysia due to his vast experience in dealing with structure repairs and modifications. He participated in the Master Programme conducted by University of Surrey, United Kingdom as part of drive for Malaysia Airline to be the Emerging Technology Center. He obtained the MSc in Advanced Materials Technology in 2000. In 2001, he joined the new established KLIA Technical Services and later became an Acting Senior Engineer and Senior Technical Services Engineer cum Head for KLIA Engineering Operations in 2002 and 2003 respectively. He joined UniKL MIAT in early 2005 where he is now responsible for new academic programmes.

Abu Zaid Bin Abu Bakar was graduated from University of Salford, United Kingdom. He has more than 5 years of experience working in the aviation industry such as Airod Sdn Bhd and CTRM Excelnet Sdn Bhd as a Design and Support Engineer. He is now undertaking a Master programme at Universiti Putra Malaysia.