AVIONS DE TRANSPORT REGIONAL (ATR) ATR72-500 FRAME-24 CRACK FATIGUE ANALYSIS

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ABSTRACT

Typical passenger aircraft is usually susceptible to heavy landing, fatigue due to expansion and decompression of the cabin, and receiving lots of other external and internal load which eventually causing certain load-bearing structure to be defective, cracked or delamination especially for the composite structures.

The idea of this study was initiated from several ATR 72-500 frame 24 cracks that were found during hangar inspection after reaching approximately 24,000 flight cycles. Thus, with regards to this statement, this paper aims to investigate the root cause of the crack and predict the crack occurrences on the frame 24 of the ATR 72-500.

By understanding the load exerted and other accounted factors contributing to the crack and its growth, one will be able to find the root cause, provide clearer insights of the process and propose better repair scheme or certain required modification in order to enhance the lifespan of the respective structure. Various methods are being discussed, however the author intent to focus on using finite element method using computer aided engineering in order to simulate the expected results. Thus, by confirming it will be having crack propagation when reaching the required cycle will help operators in preparing suitable maintenance activities to rectify the problem before it occurs.

ABSTRAK

Sudah menjadi suatu kebiasaan bagi pesawat penumpang mudah terdedah kepada pendaratan berat melebihi kadar kebiasaan, kelesuan struktur akibat pengembangan dan penyahmampatan kabin serta menerima pelbagai beban sama ada dari dalaman mahupun luaran yang sekaligus menjadikan struktur yang menggalas atau menerima beban itu menjadi cacat, retak atau penyimpangan atau delaminasi jika membabitkan struktur komposit.

Gambaran kasar tentang pengkajian ini bermula apabila beberapa buah pesawat ATR72-500 ditemui mempunyai keretakan pada kerangka bingkai-24 ketika dihantar untuk cek utama apabila kapal menghampiri 24,000 kitaran penerbangan. Maka, berpandukan penyataan ini, kertas projek ini diperkemas dengan tujuan menyiasat punca sebenar dan menjangka kebarangkalian kejadian keretakan yang sama berulang ke atas bingkai-24 untuk pesawat ATR72-500

Dengan memahami daya yang bertindak ke atas sesuatu struktur pesawat itu dan mengambil kira faktor-faktor penyumbang seperti keretakan dan pertumbuhannya, individu terbabit mampu mencari punca sebenar yang menyebabkan berlakunya keretakan itu, memberi gambaran yang lebih jelas bagaimana proses itu terjadi lantas memberi cadangan dan panduan skema pembaikan dan modifikasi bagi memanjangkan jangka hayat sesuatu struktur terbabit. Pelbagai cara dapat dibincangkan; walau bagaimanapun, tujuan penulis dalam konteks kajian kali ini adalah untuk menggunakan kaedah analisis unsur terhingga menggunakan program kejuruteraan terbantu komputer untuk mensimulasikan jangkaan keputusan. Lantaran, pengesahan yang dilakukan melalui kaedah ini, dapat memastikan sesebuah pesawat mulai mencapai kitaran penerbangan yang dijangkakan maka secara langsung membantu pengendali pesawat untuk lebih bersedia dalam menghadapi, merancang dan menyediakan plan-plan pembaikan kepada kerosakan terbabit.

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Let's go even further (together).

APPROVAL

This thesis was submitted to the Senate of Universiti Pertahanan Nasional Malaysia and has been accepted as fulfilment of the requirements for the degree of **Master of Science in Engineering (Aeronautics).** The members of the Supervisory Committee were as follows.

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The Examination Committee has met on **2nd February 2019** to conduct the final examination of **Muhammad Hanafiah bin Mohsin** on his degree thesis entitled **‘Avions de Transport Regional (ATR) ATR72-500 Frame-24 Crack Fatigue Analysis’.**

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Date: 15th April 2019

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Academic session	: March 2018 – March 2019

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CHAPTER 1

INTRODUCTION

1.1 Background

Firefly Airlines which is a subsidiary of the Malaysia Airlines Group currently operates 12 ATR 72-500. Despite being an aircraft operator, the company also runs a Maintenance Repair & Overhaul (MRO) centre to support its ATR fleet. It also inducted other MAG subsidiaries ATR 72 aircraft for major checks.

As there are many maintenance activities required to be carried out in certain hangar checks, various panels and access to any of the aircraft frames ranging from frame number 1 (which indicates the first and most front frame) up to the very end including the pressure bulkhead are being removed and opened. This is done in order to carry out required maintenance activities which consist of periodical inspection, assessment and operational checks to identify defects. The objective of this inspection is to find any abnormalities or defects on the aircraft components such as corrosion, undetectable crack that was not being able to be seen by the bare eyes which requires certain non-destructive testing methods such as dye penetrant inspection, high frequency eddy current (HFEC) and thus eliminating other potential yet hidden damages that could lead to catastrophic failures.

1.2 Problem Statement

An aircraft ideal condition would mean that it is enable to operate up to its design service goal (DSG) which varies differently among types of aircraft based on its size and maximum take-off weight (MTOW) without having any structural or integral part failure. Certain aircraft like Boeing 747 have maximum of 100,000 flight cycles or 25 years before reaching its DSG; other smaller aircrafts like ATR 72 possess slightly lower maximum DSG of 75,000 flight cycles. This DSG figures indicates that the aircraft able to be operated up to 75,000 flight cycles without any major problems which also indicates the idealistic environment where the aircraft is being operated.

However, it was reported that ever since Firefly’s aircraft base maintenance program took place, there were 7 aircrafts which were being inducted into the Firefly’s Subang Hangar for major maintenance was found with cracks on the frame 24. Similar defects and occurrences were being reported on the same area and at the same spot (only differentiating between left-hand and right-hand side respectively).

In Malaysian region, there are only 3 aircraft operators that utilizes ATR72 which are Firefly Airlines, Maswings and Malindo Airways. As per communication with representative from these regional airliners, only Firefly and Maswings reported to have similar defective crack on similar area. The similarity in the aircraft between these two companies are in terms of high daily flight cycle usage which consists of up 10 flight cycles; and both affected companies’aircraft had accumulated more than 20,000 flight cycles since manufactured.

Typically, the flight cycle is defined based on the Out, Off, On, In (OOOI) system which a representive of an actual aircraft movements of Gate Out, Wheels Off, Wheels On, and Gate In. However, from a structural perspective, it also means that it is the number of the cycles that aircraft had flown and had undergone compression and decompression stress. Thus why it is important to keep the flight record data such as flight hours (FH) and flight cycles (FC) up-to-date.

Among the aircrafts that affected were 9M-FYA (with 22191 flight hours, 24631 flight cycles); 9M-FYB (with 21336 flight hours, 23463 flight cycles); 9M-FYC (with 21023 flight hours, 23118 flight cycles 9M-FYE (with 22958 flight hours, 25403 flight cycles); 9M-FYF (with 21259 flight hours, 23460 flight cycles); 9M-FYG (with 21308 flight hours, 23404 flight cycles) and 9M-MWC (with 19352 flight hours, 28539 flight cycles). This failure is deemed unacceptable as the frame 24 which is an integral part of the aircraft is supposed to reach its fatigue limit in line or close to the aircraft's DSG.

From the list mentioned, it was evident that 3 out of 7 aircrafts reaching 24000 flight cycle was found having the frame 24 crack; leaving another 4 occurrences below the 24,000 flight cycles.

These benchmarks are very important in assisting airline or any other aircraft operators as it will allow them to be more prepared in sense of tool preparation, ground time and manpower to carry out the frame 24 replacement which is crucial in the operator's planning and aircraft turnaround. Having an unscheduled removal of certain components on the aircraft; be it either frame, engines, flight control surfaces and so on will hinder the aircraft operation thus promoting loss in terms of reliability, profit and trust from customers.

There are two ways in order mitigate this issue which is through preventive maintenance by predicting approximately when the crack on the frame will occur based on previous working experiences; another one is based on the inspection of the condition of the frame from certain period and replace it directly when discrepancies are found.

Thus, this paper will look on the first method where it is based on two approaches which is first to determine that the frame will indeed fail at certain cycles and second is to provide enhancement on the current frame design that will prolong the predicted cycle for the frame enable to withstand.

1.3 Objective of Study

As the scope of this study is quite big, this paper tend to focus on two most deemed important aspects from the perspective of airline or aircraft operators which are:

I. To identify the forces or loading that caused the crack

II. To predict the crack occurrences on the frame 24 of the ATR 72-500

Thus , in order to achieve these objectives, computer aided engineering method is being applied which the respective frame 24 is being modeled in Solidworks® software. After similar model had been drawn as per the real frame, a typical load which consist of static loading to represent the aircraft in parking condition and loading during landing condition is simulated and exerted onto the frame-24. This is done in order to represent important loading from complete flight profile ranging from aircraft chocks off, undergoing normal taxiing, take-off, cruise, landing and taxiing back until the aircraft return to chocks is being exerted. Despite This process is being repeated for 24,000 cycles to further simulate similar cyclic loading acting on the frame.

1.4 Scope of Work and Limitations

The scope of this simulation focused only on frame-24 which is only one, upper segment of the circular frame. Furthermore, it only focuses on the load acting on a single frame over other 54 pressurized, load-taking members of the ATR 72-500. As there are various forces acting on various directions on the frame during all flight phases, this research investigates only on the uniformly distributed static loading and vertical load acting at the end of the frame which is to simulate aircraft during landing condition and taxiing or parking while on ground respectively.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In order to grasp a better understanding of the problem, the component affected must be identified and located with regards to its location on the aircraft. Following picture pinpoint the location of the frame-24 with reference to the whole fuselage on the regional ATR 72-500.

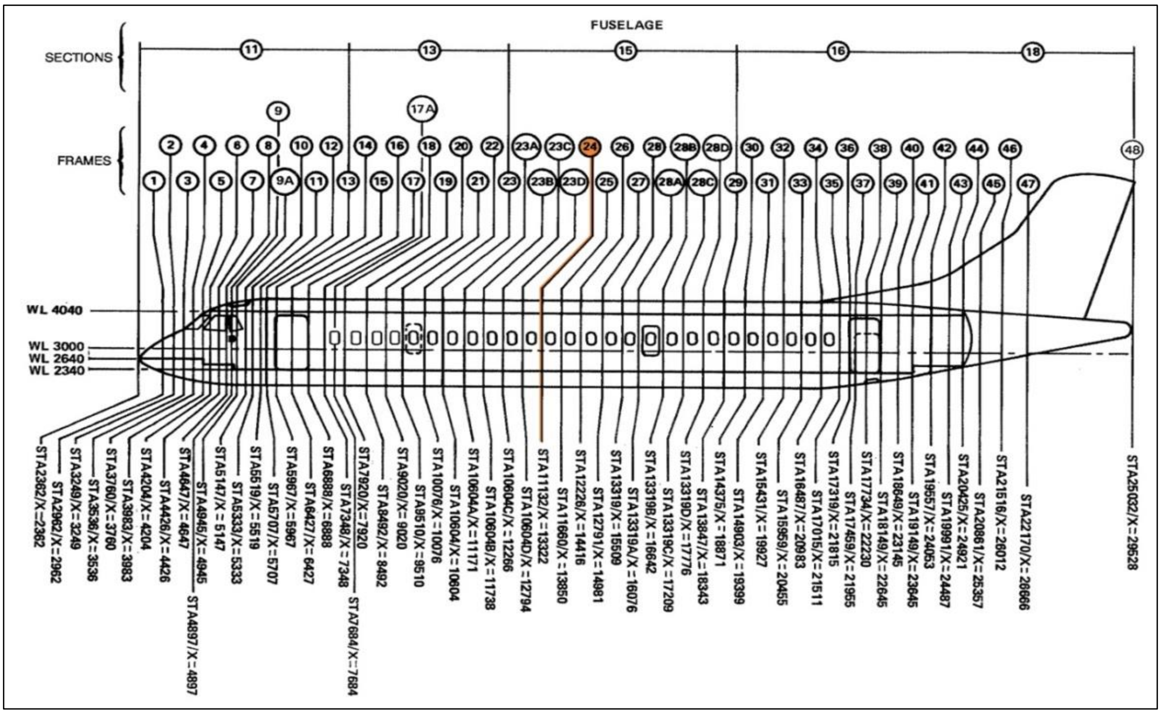

Figure 1 Location of the Frame 24 with Reference to Fuselage **[1]**

From Figure 1, it is shown that the frame-24 (highlighted) is situated in section 15, zone 200 which is located at the center section of the aircraft's fuselage. This makes it even more susceptible to major impacts of hard landing. Various factors such as hard landing occurrences, landing speed, touchdown speed, landing angle, maximum take-off weight (MTOW) and components such as landing gear that is attached to the frame, fixed unmovable joints such as stringer crossing path with frame plays an important role in determining the result required.

In order to highlight the failure of the frame-24, a much simplified table indicates the total flight hours and flight cycles when the respective component was found defective.

Table 1 List of Affected Aircraft that had Been Inducted due to Frame-24 Crack

Tail Number	Aircraft Model	Total Flight Hours	Total Flight Cycles
9M-FYA	ATR 72-212A	22191	24631
9M-FYB	ATR 72-212A	21336	23463
9M-FYC	ATR 72-212A	21023	23118
9M-FYE	ATR 72-212A	22958	25403
9M-FYF	ATR 72-212A	21259	23460
9M-FYG	ATR 72-212A	21308	23404
9M-MWC	ATR 72-212A	19352	28539

Similar pattern can be seen as the crack was found closely after 20,000 flight cycles. Furthermore, in order to grasp the understanding of aircraft operation as a whole, the following flight profile is shown.

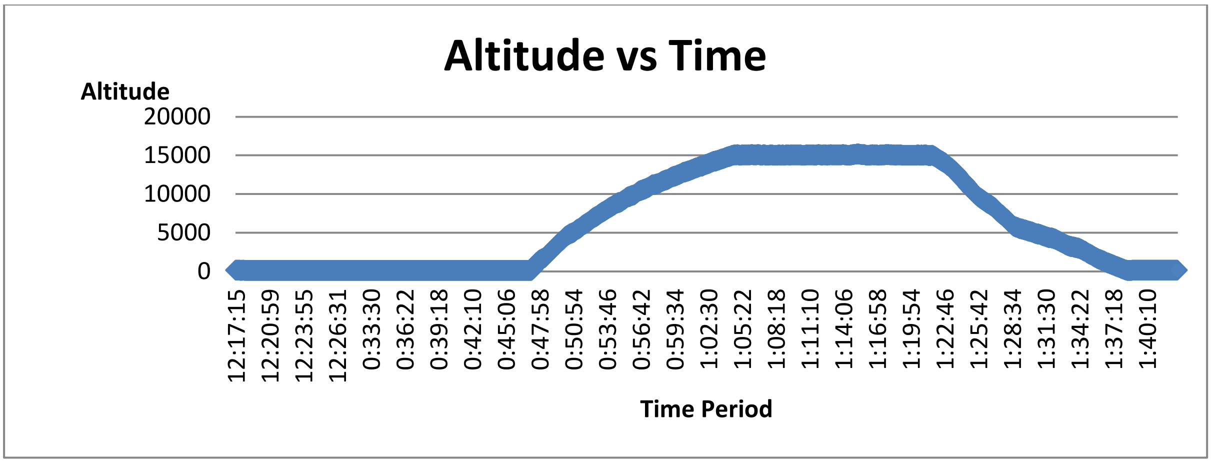

Figure 2 Firefly's Typical ATR 72 Flight Profile based on Data Acquisition System

As per Figure 2 shown, a flight profile for the aircraft can be deduced which typically consist of taxiing and preparing for take-off. The aircraft also is seen descending as it gets closer to the arriving runway.

2.2 Hard Landing

As there are various factors that trigger damages on certain fuselage structure, this paper aims to include among common incidents that occurred during airline operations which are the hard landing. The sudden urge of load exerted on the member does inflict further damages and displacement onto the integral part of the aircraft such as load carrying member such as frames and longerons.

According to an article written by Ibold Ken, landing accidents accumulates more than one third of all generation aviation accidents [2]. Despite his claim that landing accidents are not usually as disastrous as other types of crashes where only 3 to 4 per cent of fatal accidents consist based on poor landings, hard landings were deemed important in causing approximately 500 bents per year which bears high load on the fuselage structure not only on the lower portion of the fuselage, but also causes compression and decompression on other sections of the aircraft especially fuselage.

Hensellek conveyed regarding a statistic where the frequency of aircraft incidents or damages are due to hard landing surpass the other causes of air catastrophe such as airplane overshooting the runway, departing excursion of the runway and landing gear failure [3]. According to a source from an article written by Flight Safety Foundation Editorial Staff, hard landings are the highest cause for aircraft accidents worldwide [4]. Thus, there are certain routine maintenance procedures to be carried out if such incident took place such as oleo or shock absorber servicing, main landing gear and fuselage detailed inspection. Many aircraft typically undergo repair process and started flying back again quickly once the proper repair scheme had been carried out. This will slow down the aircraft operation and jeopardize customers' trust due to aircraft not being serviceable in order to carry out the rectification process.

However, further added by Hensellek, it is the responsibility of the pilot to land as swiftly as they could and prevent any hard landings which could cause excessive structural loading as they are the only capable to manoeuvre and ensure minimal damage between the fuselage and the upcoming runways during approach; which will be determined if the impact will be high enough to be considered as a hard landing [3]. Nevertheless, Hensellek reiterates that there were no formal universal definition of a hard landing except stated in certain publications such as The National Transportation Safety Board (NTSB) defines a hard landing in The NTSB Coding Manual as "stalling onto or flying into a runway or other intended landing area with abnormally high vertical speed" [5] whereas according to the Federal Aviation Administration (FAA) in one of its publication considered that any sink rate in excess of 800-1000 feet per minute is abnormally high; this vertical sink rate can lead to hard landing but also being categorized as having less damaging similar to firm landing [6]. Hensellek futher reemphasized that it is a subtle differences between a firm landing and hard landing in terms of sink rate, angle of descent, descend speed as well as how the pilot flew which could be subjective; but nevertheless it important to differentiate these mentioned criterias in order to prolong aircraft structural integrity [3].

2.2.1 Crashworthiness

Most of the articles and researches focused more on crashworthiness instead of hard landing. As compiled by Siromani that during an aircraft crash regardless of wide or narrow body; the emergency landing will most likely to cause the landing gear to collapse, and exerting high impact on its fuselage [7].

Siromani further reinforced that in a situation when aircraft undergoing an impact, the kinetic energy will be absorbed by the aircraft structure and the resultant force and decelerations that being transmitted through the passenger seats and its restraint system need to be reduced to a more tolerable and endurable level [7]. Waldock specified crashworthiness differs from the usual hard landing, whereas in the context of crashworthiness studies, it is more focused on reducing the chance of occupants' injuries and reducing the airframe structural damage and payload [8]. Thus, in order to lower the propensity of the injuries and fatalities and decreasing the magnitude of impact, larger energy is required to be absorbed by the airframe structure as mentioned earlier by Siromani [7], which further caused more damage on the airframe structure, thus could be one of the majoring factor that contributes to the frame-24 crack. Thus, the perspective of assessing the impact of the aircraft on hard surface is fairly important.

2.3 Fatigue Cracks with regards to Cyclic Loading

Fatigue cracks are very important especially in the engineering field pertaining aerospace industries as it does not only concern safety factors but also directly affecting the passengers which the damage could be fatal [9]. Haydar also stated that it is fairly important to assure the reliability of critical components which directly affected by the precise crack path occurrence and fatigue life estimation. In order to tackle the issue better, it is of the utmost important for one to understand what fatigue is According to Jones, fatigue is an engineering term which differs from the colloquial definition of material weariness and involves crack which can be found at developmental stages and continue propagating [10] Hoeppner on the other hand furtuer specified on cyclic loading to be part of basic fatigue considerations; as the application of repetitive or fluctuating stresses, strains or stress intensities to certain locations on the structural components; where degradation that might occur on the said area is being referred as fatigue degradation [11]. To complement this, Suresh in his book pertaining fatigue of materials, had stated that most common failure occurrences in the machinery or structural components can be directed back to fatigue [12]. Following figure indicates the basic fatigue considerations on mechanical deformation with regards to cyclic loading.