UNIVERSITI PUTRA MALAYSIA

EFFECTS OF AERODYNAMIC LOADING ON THIN SUBSTRUCTURE WITHIN TRANSONIC REGION OF SUBSONIC AIRCRAFT

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Engineering

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Chairman : Associate Professor Ir. Faizal Mustapha, PhD
Faculty : Engineering

As early as 2 months into service of Malaysia Airlines A380, flight crew reported fluttering noise within the vicinity of the upper deck door at position 2. Upon further inspection, it was found that a thin metal with non-metal composite substructure covering a void area on top of the aircraft door damaged. The substructure, also known as coverplate was replaced, however, within short cycle duration, the same component failed again.

Located at slightly aft of the wing to fuselage junction, these damages confined only at this position although the same substructures are in placed on all the doors. After subsequent replacement, the mounting area on the door skin was found to be cracked. Mechanical analysis was performed and found that the fatigue life of the aluminium 2024 skin was used up by a flutter phenomenon.

Precious ground time involved in repairing these cracks which extended to the whole door replacement pushes for an immediate solution to be made available. Adding to that, the risk of an inflight failure which may leads to a rapid decompression is too great for this problem to be taken lightly. Safety, cost, passenger comfort and company image are among the factors leading to these extensive studies.

Unlike any previously known defect on the aircraft, of which the root cause of the problem can be easily identified and addressed quickly, this particular issue however, baffled all parties including the manufacturer as it affected A380 fleet all over the world.

Compressible CFD simulation was conducted in finding the cause of this flutter. Of all the coverplates, only at this particular position; during cruise, an awkward pressure gradient occurs along the longitudinal axis of the substructure. This triggers the lifting of the forward edge of the part while the ram airflow causing it to peel out further. Once the shape distorted and the pressure equalized; due to its flexibility, the cover returns to its original position. The cycle continues. 4 different coverplate designs with varying stiffness being introduced to elevate this issue, all failed, and some even aggravated the damages to the door skin. However, basing from this study, an aerodynamically optimized coverplate was produced and tested over a period of 1 year at this specific location; no further damage was found and it was embodied as a permanent fix to this issue.

These findings managed to highlight that even for a subsonic aircraft, the occurrences of a transonic region within the fuselage is a prevalence that require some detail attentions during the design stage. This is an important consideration prior to the placement of any exterior parts such as these coverplates, antennas, drain masts or probes that may protruded into the airflow where shockwaves could have formed and caused unforeseen effects.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Kejuruteraan

KESAN TERHADAP SUBSTRUKTUR NIPIS PADA PINTU DALAM RUANGAN PERANTARA BUNYI UNTUK KAPAL TERBANG SUBSONIK

Oleh

UMRAN BIN ABDUL RAHMAN

Februari 2018

Pengerusi : Profesor Madya Ir. Faizal Mustapha, PhD
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Seawal 2 bulan pertama perkhidmatan Malaysia Airlines A380, anak kapal melaporkan bunyi getaran yang kuat di persekitaran pintu dek atas pada kedudukan 2. Setelah diperiksa, didapati bahawa sebuah substruktur yang terdiri dari campuran logam dan bukan logam yang meliputi ruangan kosong di atas pintu tersebut telah rosak. Substruktur tersebut yang juga dikenali sebagai ‘coverplate’ digantikan, bagaimanapun, dalam tempoh kitaran yang singkat, komponen yang sama gagal lagi.

Pintu dek atas berposisi kedua ini berkedudukan sedikit ke belakang dari persimpangan di antara badan dan sayap kapal terbang, di mana kegagalan ulangan substruktur ini hanya terbatas pada kedudukan ini sahaja walaupun substruktur yang sama dipasangkan pada setiap pintu. Selepas penggantian berikutnya, kawasan pemasangan pada kulit pintu itu didapati retak. Analisa mekanikal telah dilakukan dan didapati bahawa jangka hayat lesu kulit aluminium 2024 telah tamat digunakan oleh satu fenomena getaran.

Banyak masa yang berharga terlibat dalam membaiki keretakan ini. Bukan itu sahaja, proses membaik pulih pesawat juga ada yang melibatkan penggantian pintu yang baru. Ini memberi tekanan kepada semua yang terbabit untuk mendapatkan penyelesaian segera. Selain dari itu, risiko kegagalan dalam penerbangan yang boleh menjurus kepada kehilangan pemampatan kabin adalah terlalu besar untuk membiarkan masalah ini berlanjutan dengan lebih lama. Keselamatan, kos, keselesaan penumpang dan imej syarikat adalah di antara faktor yang mendorong kepada kajian yang menyeluruh ini.

Tidak seperti kebanyakan kegagalan struktur atau sistem pesawat yang lampau, di mana puncanya agak mudah dikenal pasti dan segera ditangani, punca kegagalan yang dihadapi kini bagaimanapun, masih lagi kabur serta mengelirukan kesemua pihak termasuk pembuat pesawat kerana ianya melibatkan keseluruhan pesawat A380 di serata dunia.

Simulasi CFD mampat telah dilaksanakan dalam mencari punca berlakunya getaran ini. Daripada kesemua substruktur, hanya pada kedudukan ini sahaja; semasa pelayaran, kecerunan tekanan udara yang janggal berlaku di sepanjang paksi membujur substruktur. Ini mencetuskan daya angkat pada bahagian hadapan substruktur di mana kelajuan ketara udara yang mendatang mengakibatkannya terus lagi terkupas keluar. Apabila bentuk telah terlentur dan penyamaan tekanan udara berlaku; oleh kerana kelenturan struktur, penutup ini kembali kepada kedudukan asal. Kitaran ini berterusan. 4 reka bentuk ‘coverplate’ telah diperkenalkan dengan perbezaan tahap kekakuan, kesemuanya gagal malah ada diantaranya yang mengakibatkan kerosakan yang lebih teruk kepada kulit pintu pesawat. Bagaimanapun, berkisarkan daripada kajian ini, sebuah ‘coverplate’ baru yang dioptimumkan secara aerodinamik telah diuji dalam tempoh 1 tahun untuk lokasi ini; tiada kerosakan lanjutan ditemui dan ianya telah dijadikan sebagai satu penyelesaian kekal.

Penemuan ini berjaya menunjukkan bahawa walaupun pesawat subsonik, kejadian sesuatu kawasan perantara bunyi pada badan pesawat adalah kelaziman yang memerlukan perhatian terperinci semasa peringkat reka bentuk. Ini adalah satu pertimbangan yang penting sebelum menempatkan sebarang peralatan luar seperti coverplate ini, antena, struktur pengaliran atau kuar yang boleh berada di dalam aliran udara di mana gelombang kejutan dapat terbentuk dan menyebabkan kesan yang tidak diduga.

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I certify that a Thesis Examination Committee has met on 21 February 2018 to conduct the final examination of Umran bin Abdul Rahman on his thesis entitled "Effects of Aerodynamic Loading on Thin Substructure within Transonic Region of Subsonic Aircraft" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Engineering.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Engineering. The members of the Supervisory Committee were as follows:

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I hereby confirm that:

- this thesis is my original work;
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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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LIST OF ABBREVIATIONS

CFD	Computational Fluid Dynamics
CG	Centre of Gravity
CNC	Computer Numerical Control
EASA	European Aviation Safety Agency
FE	Finite Element
FSI	Fluid Structure Interaction
FVM	Finite Volume Method.
HFEC	High Frequency Eddy Current
LES	Large Eddy Simulation
NDT	Non-Destructive Testing
OpenFOAM	Open source Field Operation and Manipulation
RANS	Reynolds Averaged Navier-Stokes
SIMPLE	Semi Implicit Method of Pressure Linked Equations
SST	Shear Stress Transport
STL	Stereolithographic

CHAPTER 1

INTRODUCTION

1.1 General Introduction

Aircraft is a complex machine. It may seems like a mundane thing to the current generation, nevertheless, the principle behind it is still vaguely understood by many. Designing an aircraft may sparks from such a humble beginning where a bunch of friends while having a cup of tea at a coffee shop somewhere, talking about it while a used envelope serves as the victim of unscrupulous sketches, yet it may leads to an actual production of an aircraft!

The current design approach which involved conceptual, preliminary and finally detail design is widely accepted as a standard in the aircraft design methodology. Touching on design stages, the final detail design, although being termed 'design', it goes hand in hand with the production of the parts of the aircraft. This mixture of design and production may avoid changes to the prefabricated aircraft parts or sub-assemblies. Modeling and testing also intensifies during this stage. As much as the designer would like to complete a flawless design, nevertheless, we need to accept the fact that we are still humans and as such that we may oversight things.

This thesis, although it will be based more on investigative research, the primary objective however, is to highlight the importance of detail load analysis during the design processes of external substructure even though those structures deemed as less significant compared to the main structural components.

The advancement of today's communication technology which sees the need for a constant connectivity even during flights, pushes for the Aircraft Manufacturer to provide an option for additional satellite antenna installation on the exterior of the aircraft. The location of installation needed to be checked not only for reception effectiveness but it must also be cleared from any would be pressure spikes or interferences due to primary structural junctions. Since this research is an industrial based, it is more appropriate to provide some background data on the industrial players involved.

1.2 Malaysia Airlines

Back in Colonial period, in 1947, Malayan Airways was born. Ten years later, after the independence of Malaysia, the name was changed to Malaysian Airways. Within a few years of the liberation of Singapore from Malaysia, Malaysia-Singapore Airlines was officially formed. In 1972 however, this company split into two separate entities, Malaysia Airlines System, and Singapore Airlines. In September 2015, Malaysia Airlines System was changed to Malaysia Airlines Berhad.

Today, Malaysia Airlines operates with 6 AIRBUS A380, 19 AIRBUS A330 and 57 Boeing B737 while Firefly and MASwings (which are direct subsidiaries) operate using ATR-72 and DHC Twin Otter. Similar to any other Airlines, continuous changes of fleet types and numbers are expected as the needs, efficiencies, or advancement in the industry occurs. From the latest update, Malaysia Airlines will be adding 6 AIRBUS A350 into its fleet.

1.3 AIRBUS

In 1974, AIRBUS Industry rolled out A300 and became the first twin-engine wide body aircraft in civilian aviation. Since then, AIRBUS continuously progress with more and more advances in the aviation industry to a point where it became a trendsetter in civil aviation. The application of fly-by-wire concept which was only acceptable in the military application gained momentum in civil aviation by the introduction of A330 families in the early nineties. This concept cuts down the heavy structural issues in dealing with the mechanical cable system for the flight controls.

Together with the introduction of A330, AIRBUS also introduced the Active Centre of Gravity (CG) trimming. With it, the increased in fuel efficiency achieved by precisely positioning the aircraft CG (by moving the fuel around) instead of trimming the horizontal stabilizers (which will eventually add drag) for straight and level cruising flight. This net effect on the reduced fuel consumptions per payload weight obtained a high degree of acclamations from the Airline community all over the World. The net reduction of drag is just one of its advantages; while on the final landing approach, all the outboard fuel being transferred into the central portion of the aircraft. With lighter outboard mass of the wing, expectedly the wing spar loading during touch down impact will be lessened.

AIRBUS Industry, being a consortium, continuously paves the way for applying latest advances in technology into commercial aviation. These latest advancements can be seen in A380, A350, and A320neo. The use of metal to non-metal composite materials, relatively fast on-board computing systems, and self-powered flight control actuation systems, are some of the applied advances in the current production aircraft. Poor fuel efficiency linking to conventional approach in aircraft design may render obsolete in this new era, as all these innovations are geared toward a high level of safety while reducing the net operating cost.

1.4 Malaysia Airlines and A380

In the year 2003, Malaysia Airlines decided to place the order of six AIRBUS A380 after its official launching. On May 29th, 2012, Transfer of Title took place in Toulouse, France for the first A380 delivery for Malaysia Airlines. The A380 fleet registrations followed the requirements laid down by the Department of Civil Aviation, Malaysia. The tail number of the first aircraft is 9M-MNA and followed by the second, MNB and so on until the sixth aircraft which is MNF. On 1st July 2012, Malaysia Airlines conducted the inaugural flight to London, and officially the fleet enters into service. Since the arrival of the 6th aircraft, with twice daily to London, daily to Hong Kong while in between daily to Paris, the average flight time utilizations per aircraft are around 13 hours per day. This utilization rate is in line with the current industry standard. Optimization of aircraft flight hours such as this, is an important measure for any Airlines in obtaining the proper return of investment.

So far, most of the key players including some surface knowledge of the actual issue which motivated this research have been presented. However, there are still entities which have not been mentioned such as UPM and software developers and will do so concurrently, and with that, the presentation of the actual problem and motivation will follow through.

1.5 Problem Statement and Motivation

Airlines, as everyone knows, are a business entity. Apart from rigorous marketing and strategy, the involved machines (aircraft in this context) must be as reliable as it can be and low at operating and maintenance cost.

When an aircraft fleet plagued with an issue, then the business objectives will not be met and not only that, the premium image potrayed by the Airlines will also be jeopardised. It is, therefore, vital for the Airline to find a proper solution for any plaguing issues as quickly as possible in preventing a huge capital out flow.

As early as August 2012 i.e. within a month of operation, on MNA, there are reports on Upper Deck Door 2 (U2 in Figure 1-1) generating flapping noise during flight (refer to Table 3-1 for the staggering number of noise reports during the first year operation of this fleet). Upon detail inspections, it was found that the door coverplate delaminated and as per the Aircraft Maintenance Manual (AMM) it must be replaced.

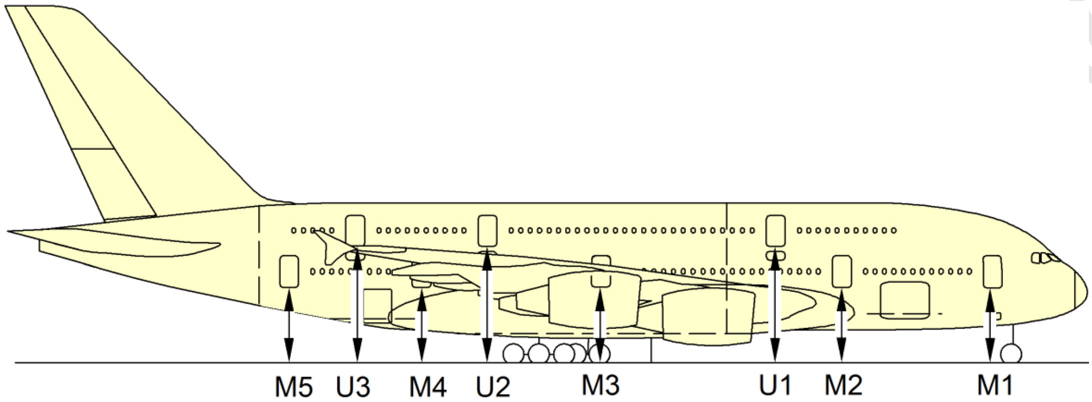

Figure 1.1 : A380 Door Layout (Courtesy from AIRBUS AMM)

Figure 1.2 : Actual A380 U2 Door Problem Area

Apart from the overwhelmed logistics involved in getting this part replaced, the additional maintenace ground time required means, the availability of the aircraft to provide the required services halted. This pushes other aircraft to take over its duty and their (the replacement aircraft) required ground time for maintenance jeopardized. In other words, unscheduled maintenance will caused a snowball effect. Although what has been conveyed here involving Malaysia Airlines, other Airlines also suffers the same problem, reference [19], [20] and [1] are some of the news clippings involving flight incidences of these A380 door issues.

The issue becomes chronic when the door skin itself cracked after some time. Not only that, all the 6 aircraft were affected with the same defect at the same location. The complexity of the underlying issue will be further discussed in Chapter 3. While this research is on going, EASA (European Aviation Safety Agency) issued an Airworthiness Directive [17] for the operators to carry out detail structural inspection on all the A380 passenger doors.

Under normal scenario, any typical issue similar to this, Airlines will bank on the Manufacturer for a speedy solution. Through out history, back in the mid nineties during the induction phase of A330 fleet to the world, similar issue cropped up [77]. While it seems simple enough to enhance the mechanical property of the VHF antenna, the problem back then was egravated further i.e. the skin area where the antenna mounted was found cracking post antenna modification. Apart from strengthening the skin, the final fix was to shift the location of this VHF antenna as it was found that harmonic induced flutter was at its peak at this particular location. Coming back to this current issue, the quickess posibble solution will be to enhance the mechanical strength of the coverplate assembly and AIRBUS did just that. However, after series of modifications, the issue still very much alive and things are getting worst as the real reason behind the failures were still unknown. This is where, although this is design specific issue, the knowledge gap needed to be closed in preparation for future aircraft designs.

In the VHF case quoted in the above paragraph, AIRBUS took roughly 3 years to get it solved and this lengthy time scale is simply unacceptable by Malaysia Airlines as there are no other fleet within the system (at that period of of time) to accommodate for the long-haul scheduled flight. All in all, safety, discomfort, prolonged ground time and escalating maintenance cost are the primary movers behind this study.

1.6 Research Objectives

The objectives of this research are as follows:

1. To analyse the aerodynamic loading on the thin substructure attached to the door assembly located around the expected transonic region of a high subsonic passenger aircraft.

2. To investigate the root cause of the recurring damages to the aircraft door via simulating the airflow behavior through a CFD approach.
3. To deduce optimal solution on the defected door via the collaborations between the operator and the manufacturer in order to reduce safety risks and maintenance burden.

Findings of this study will assist the manufacturer and the operator directly to reduce if not eliminate this issue altogether. Besides that, the study itself will expose some design considerations that is to be taken into account while designing future commercial aircraft. This is especially important for the placement of the entry or service doors around the wing to body junction, where unsuspecting odd aerodynamic forces may occur and a costly re-design work required as a consequent to the effect. Even if a designer of an aircraft needed to place any other components such as an antenna or drain masts around this region, based on the projected output of this study, a thorough airflow analysis would be needed in preventing similar occurrences. In a long run, perhaps future aircraft design courses shall include the findings of this study as part of the standard syllabus.

1.7 Scope of Studies

Although the data obtained from the operator conferences conducted by the manufacturer have shown that this door issue on A380 is global in nature [2], this study however, focuses only on Malaysia Airlines aircraft. To elaborate further, refer to this press conference [28] given by Tom Williams (AIRBUS Chief Operating Officer) especially between 17th to 21st minute, which was published on June 12th 2014. Via effective colloborations between all involved entities, the results of this research will be the guiding principles in solving the issue.

Due to proprietary issues involving the Airlines and AIRBUS, in general, only publicly available data will be used. Nonetheless, if publicly unpublished data are still required in supporting the study, proper acknowledgment will be made accordingly in presenting them.

1.8 Thesis Layout

As already presented, in this Chapter the major plot players being briefly identified together with the actual problem and the motivation of this study. This is of course just touching the base of everything that will be presented in this dissertation.

In the early part of Chapter 2, basic desciptions of the subject aircraft will be conveyed. Following which, the presentation on the design, operational concept, and the construction of the door and its effected component will be made. This will offer the needed supplements in comprehending the nature of those problem statements made in subtopic 1.5. To enhance further, several study options will also be added in Chapter 2, at which the deduction for the final study method together with the involved literature reviews will be presented. All the involved variables used to present the mathematical model will be made known in-situ to ease comprehension.

The above decision on the final methodology was not only based on the problem itself as due considerations were also given based on the results from the analytical study as well as the discussion on the hypothetical failure scenario. These deliberations will be revealed in Chapter 3 together with the detail presentations of the methodology involved in meeting the objectives.

In Chapter 4, full disclosure of the results obtained from the simulations can be reviewed. An extensive validation work of the used codes together with the validation of the actual simulation will also be presented. Out of these results, final deductions will be made. Chronological events and steps as well as the time taken to evaluate and subsequently satisfy that the issue is eliminated altogether being presented.

In the final Chapter, the closure of the objectives were made together the future study options.

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