

**DYNAMIC STABILITY
ON LATERAL DIRECTIONAL OF AN AIRCRAFT USING AILERON**

HEW KHAI SHENG

**A report submitted
in fulfillment of the requirements for the degree of
Bachelor of Mechanical Engineering (with Honours)**

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

DECLARATION

I declare that this project report entitled “Dynamic Stability on Lateral Directional of An Aircraft Using Aileron” is the result of my own work except as cited in the references.

Signature :

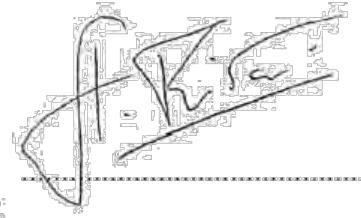
Name : HEW KHAI SHENG

Date : 6 JUNE 2018
.....

APPROVAL

I hereby declare that I have read this project report and in my opinion this project report is sufficient in terms of scope and quality for the award of degree of Bachelor of Mechanical Engineering (with Honours).

Signature :

A handwritten signature in black ink, appearing to read 'MADYA AHMAD RIVAI', is written over a horizontal dashed line. The signature is stylized and somewhat cursive.

Name : PROF. MADYA AHMAD RIVAI

Date : 6 JUNE 2018

DEDICATION

Dedicated to my beloved father and mother,
my friends and family members.

For their encouragement and supports throughout the research.

ABSTRACT

The dynamic stability analysis of the aircraft can be evaluated in two dimensional modes: longitudinal stability analysis and lateral directional stability analysis. This present work focuses on the second mode which is lateral directional. The dynamic stability analysis is carried out by evaluating the behavior of three flight parameter due to aileron deflection. These three flight parameters are sideslip angle β , roll angle ϕ and yaw angle ψ . These three flight parameters describe the behavior of the aircraft in lateral directional and it can be obtained by solving the governing equation of lateral directional. In this present work, a computer code is developed in MATLAB software to solve the governing equation of flight motion using Laplace transformation. The validation was carried out by comparing the results for the lateral directional of aircraft model Learjet 24 with the results provided by Marcello R. Napolitano (2012). After that, the developed computer code in MATLAB is applied to all three types of aircraft models for flight dynamic analysis. These three types of aircraft models are Cessna 182, Cessna 310, and Cessna 620. The developed computer code in MATLAB provides four types of aileron deflection, namely single doublet impulse, multiple doublet impulse, single doublet and multiple doublet. The results show that each aircraft has different response due to the deflection of aileron and the developed computer code represents a useful tool for flight dynamic analysis.

ABSTRAK

Analisis kestabilan dinamik penerbangan dapat dilakukan melalui dua mod dimensi, iaitu analisis kestabilan arah bujur dan arah sisi. Kajian ini memberi tumpuan kepada mod yang kedua, iaitu analisis kestabilan arah sisi. Analisis kestabilan ini dilakukan untuk menilai kelakuan tiga parameter akibat daripada pesongan aileron. Ketiga-tiga parameter penerbangan ini adalah sudut sisi β , sudut roll ϕ dan sudut yaw ψ . Ketiga-tiga parameter penerbangan ini menggambarkan kelakuan sesebuah kapal terbang dari arah sisi dan ia dapat diperolehi dengan menyelesaikan persamaan bagi arah sisi. Dalam kajian ini, kod komputer dibangunkan dalam perisian MATLAB untuk menyelesaikan persamaan gerakan dengan penggunaan transformasi Laplace. Pengesahan telah dilakukan dengan membandingkan keputusan untuk arah model kapal terbang Learjet 24 dengan keputusan yang diperolehi daripada Marcello R. Napolitano (2012). Selepas itu, kod komputer yang dibangunkan di perisian MATLAB digunakan untuk membuat analisis kestabilan dinamik penerbangan bagi tiga jenis model kapal terbang. Ketiga-tiga jenis model kapal terbang ini adalah Cessna 182, Cessna 310, dan Cessna 620. Kod komputer di perisian MATLAB ini menyediakan empat jenis pesongan aileron, iaitu dorongan doublet tunggal, dorongan doublet berganda, doublet tunggal dan doublet berganda. Keputusan bagi kajian ini menunjukkan bahawa setiap kapal terbang mempunyai tindak balas yang berbeza terhadap pesongan aileron dan kod komputer yang dibangunkan merupakan alat yang amat berguna untuk analisis kestabilan dinamik penerbangan.

ACKNOWLEDGEMENT

I would like to take this opportunity to express my sincere appreciation to my project supervisor, Prof. Madya Ahmad Rivai from Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka (UTeM) for giving me this chance to work together, giving me encouragement, supports and his persistently guidance towards the completion of this project.

Besides that, I would like to thank my friends and colleagues who provided me with their support and assistance throughout my journey. Lastly, special thanks to all my family members for their endless encouragement and supports in completing this project. The product of this project work would not be possible without all of them.

I am very fortunate to have them who have been giving me assistance and direction towards the completion of this project.

TABLE OF CONTENT

CHAPTER	TOPIC	PAGE
	DECLARATION	.
	APPROVAL	.
	DEDICATION	.
	ABSTRACT	i
	ABSTRAK	ii
	ACKNOWLEDGEMENT	iii
	TABLE OF CONTENT	iv
	LIST OF TABLES	vii
	LIST OF FIGURES	ix
	LIST OF APPENDICES	xiv
	LIST OF ABBREVIATIONS	xv
	LIST OF SYMBOLS	xvi
1	INTRODUCTION	1
	1.1 Background of Study	1
	1.2 Problem Statement	4
	1.3 Objectives	5
	1.4 Scope of Project	5
2	THEORY	6
	2.1 Basic Aerodynamic of Aircraft	6
	2.2 Axes of an Aircraft	8
	2.3 Aerodynamic Control	12
	2.3.1 Ailerons	12
	2.3.2 Elevator	14
	2.3.3 Rudder	16
	2.4 Stability and Control	18
	2.4.1 Static Stability	18
	2.4.2 Dynamic Stability	19
	2.4.3 Longitudinal Stability	21
	2.4.4 Lateral Stability	23
	2.4.5 Directional Stability	25
3	LITERATURE REVIEW	27
	3.1 Stability Analysis and Controller Design for the Roll Angle Control of an Aircraft by Mbaocha C.C, Obiora Valentine. T (2013)	27
	3.1.1 Methodology	28

3.1.2	Results and Discussion	28
3.1.3	Conclusion	30
3.2	A Self-Tuning Fuzzy Logic Controller for Aircraft Roll Control System by Akyazi, Ali Usta, & Sefa Akpınar (2013)	31
3.2.1	Methodology	31
3.2.2	Results and Discussion	33
3.2.3	Conclusion	35
3.3	Modeling of an Adaptive Controller for an Aircraft Roll Control System using PID, Fuzzy-PID and Genetic Algorithm by Gouthami & Rani (2016)	36
3.3.1	Methodology	36
3.3.2	Results and Discussion	38
3.3.3	Conclusion	38
4	METHODOLOGY	39
4.1	Introduction	39
4.2	Literature Study and Data Mining	42
4.3	Selection of Aircraft Model	42
4.4	Collection of Aircraft Data	44
4.5	Development of Computer Code in MATLAB	47
4.5.1	The Lateral Directional Aerodynamic Stability and Control Derivatives	47
4.5.2	The Application of Laplace Transformations to the Lateral Directional Equations of Motions	48
4.5.3	Routh-Hurwitz Analysis of the Lateral Directional Stability	53
5	RESULTS AND DISCUSSION	55
5.1	Introduction	55
5.2	Validation by Comparing Preliminary Results and Results from Marcello R. Napolitano (2012).	57
5.2.1	Preliminary Results	57
5.2.1.1	Data of Learjet 24	57
5.2.1.2	Results of Lateral Directional Responses for Learjet 24	59
5.3	The Results of Lateral Directional Stability and Control Derivatives	60
5.4	The Solution of Flight Equation of Motion using Lateral Directional Transfer Function	61
5.5	Time History and Stability Behavior in the Lateral Directional	67
5.5.1	Aileron Single Doublet Impulse	67
5.5.2	Aileron Multiple Doublet Impulse	71
5.5.3	Aileron Single Doublet	75
5.5.4	Aileron Multiple Doublet	79
6	CONCLUSION AND RECOMMENDATION	86
6.1	Conclusion	86
6.2	Recommendation	87

REFERENCES	88
APPENDIX	91

LIST OF TABLES

TABLE	TITLE	PAGE
3.1	Comparison of Different Parameters	38
4.1	Aircraft Geometric Data	45
4.2	Aircraft Flight Conditions Data	45
4.3	Aircraft Mass and Inertial Data	45
4.4	Lateral Directional Aerodynamic Coefficients	46
4.5	Formula of Lateral Directional Stability and Control Derivatives	47
5.1	Geometric Data for the Learjet 24 Aircraft	57
5.2	Flight Conditions Data for the Learjet 24 Aircraft at Cruise	57
5.3	Mass and Inertial Data for the Learjet 24 Aircraft at Cruise	58
5.4	Lateral Directional Aerodynamic Coefficients for the Learjet 24 Aircraft at Cruise	58
5.5	The Lateral Directional Stability and Control Derivatives	60
5.6 (a)	The Coefficients of Polynomials at the Numerator of β - Transfer Function	61

5.6 (b)	The Numerator of the Lateral Directional Transfer Functions in terms of β (s)	62
5.7 (a)	The Coefficients of Polynomials at the Numerator of \emptyset -Transfer Function	62
5.7 (b)	The Numerator of the Lateral Directional Transfer Functions in terms of \emptyset (s)	62
5.8 (a)	The Coefficients of Polynomials at the Numerator of ψ - Transfer Function	63
5.8 (b)	The Numerator of the Lateral Directional Transfer Functions in terms of ψ (s)	63
5.9 (a)	The Coefficients of Polynomials at the Denominator of Lateral Directional Transfer Function	64
5.9 (b)	The Denominator of the Lateral Directional Transfer Functions	64
5.10	The Lateral Directional Transfer Functions in terms of β (s)	65
5.11	The Lateral Directional Transfer Functions in terms of \emptyset (s)	66
5.12	The Lateral Directional Transfer Functions in terms of ψ (s)	66
5.13	The Maximum and Minimum Values of β , ϕ , and ψ due to Aileron Deflection	83
5.14	The Time Taken for the Aircraft to Return to its Steady State Behavior After Deflection of Aileron	84

LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	Type of Dynamic Stability	2
1.2	Basic Control-Response Relationship	3
2.1	The Forces Acting in Flight	6
2.2	The Flow of Air Around the Airfoil	8
2.3	The Three Axes of an Aircraft	9
2.4	Standard Notation for Aerodynamic Forces and Moments of Aircraft	10
2.5	Location of the Ailerons	13
2.6	Location of the Elevator	15
2.7	Location of the Rudder	16
2.8	Type of Static Stability	18
2.9	Type of Dynamic Stability	20
2.10	Neutral Longitudinal Stability	21
2.11	Negative Longitudinal Stability	22
2.12	Positive Longitudinal Stability	22

2.13	Dihedral of Aircraft Wings	23
2.14	Dihedral Effect on Lateral Stability	24
2.15	Directional Stability	26
3.1	Step Response of Roll Angle Model of Navion Aircraft	29
3.2	PID Controller with its Simple Feedback System	29
3.3	Step Response of the Closed Loop Feedback System	30
3.4	The Basic Structure of Linear Quadratic Regulator	32
3.5	The Basic Structure of Fuzzy Logic Controller	32
3.6	The Basic Structure of Self-Tuning Fuzzy Logic Controller	33
3.7	The System Response with Various Membership Functions	34
3.8	The System Response with Fuzzy Rule Tables	34
3.9	The Performance Analysis for Three Proposed Controller	35
3.10	Simulink Model of PID controller	37
3.11	Simulink Model of Fuzzy Logic Controller	37
3.12	Simulink Model of Fuzzy-PID Controller	37
4.1	Methodology Flow Chart	40
4.2	Cessna 182 Aircraft Model	43
4.3	Cessna 310 Aircraft Model	43
4.4	Cessna 620 Aircraft Model	43
4.5	The Concept of Transfer Function	50
5.1	MATLAB Start Menu for the Selection of Aircraft Model	56
5.2	MATLAB Start Menu for the Selection of the Type of Aileron Deflection	56

5.3	Lateral Directional Responses by Aileron Maneuver Obtained by Developed Computer Code in MATLAB	59
5.4	Lateral Directional Responses by Aileron Maneuver that Provided by Marcello R. Napolitano (2012)	59
5.5 (a)	Lateral Directional Responses Following Single Doublet Impulse Aileron Deflections of Cessna 182	68
5.5 (b)	Lateral Directional Responses Following Single Doublet Impulse Aileron Deflections of Cessna 182 (Zoomed)	68
5.6 (a)	Lateral Directional Responses Following Single Doublet Impulse Aileron Deflections of Cessna 310	69
5.6 (b)	Lateral Directional Responses Following Single Doublet Impulse Aileron Deflections of Cessna 310 (Zoomed)	69
5.7 (a)	Lateral Directional Responses Following Single Doublet Impulse Aileron Deflections of Cessna 620	70
5.7 (b)	Lateral Directional Responses Following Single Doublet Impulse Aileron Deflections of Cessna 620 (Zoomed)	70
5.8 (a)	Lateral Directional Responses Following Multiple Doublet Impulse Aileron Deflections of Cessna 182	72
5.8 (b)	Lateral Directional Responses Following Multiple Doublet Impulse Aileron Deflections of Cessna 182 (Zoomed)	72
5.9 (a)	Lateral Directional Responses Following Multiple Doublet Impulse Aileron Deflections of Cessna 310	73

5.9 (b)	Lateral Directional Responses Following Multiple Doublet Impulse Aileron Deflections of Cessna 310 (Zoomed)	73
5.10 (a)	Lateral Directional Responses Following Multiple Doublet Impulse Aileron Deflections of Cessna 620	74
5.10 (b)	Lateral Directional Responses Following Multiple Doublet Impulse Aileron Deflections of Cessna 620 (Zoomed)	74
5.11 (a)	Lateral Directional Responses Following Single Doublet Aileron Deflections of Cessna 182	76
5.11 (b)	Lateral Directional Responses Following Single Doublet Aileron Deflections of Cessna 182 (Zoomed)	76
5.12 (a)	Lateral Directional Responses Following Single Doublet Aileron Deflections of Cessna 310	77
5.12 (b)	Lateral Directional Responses Following Single Doublet Aileron Deflections of Cessna 310 (Zoomed)	77
5.13 (a)	Lateral Directional Responses Following Single Doublet Aileron Deflections of Cessna 620	78
5.13 (b)	Lateral Directional Responses Following Single Doublet Aileron Deflections of Cessna 620 (Zoomed)	78
5.14 (a)	Lateral Directional Responses Following Multiple Doublet Aileron Deflections of Cessna 182	80
5.14 (b)	Lateral Directional Responses Following Multiple Doublet Aileron Deflections of Cessna 182 (Zoomed)	80

5.15 (a)	Lateral Directional Responses Following Multiple Doublet Aileron Deflections of Cessna 310	81
5.15 (b)	Lateral Directional Responses Following Multiple Doublet Aileron Deflections of Cessna 310 (Zoomed)	81
5.16 (a)	Lateral Directional Responses Following Multiple Doublet Aileron Deflections of Cessna 620	82
5.16 (b)	Lateral Directional Responses Following Multiple Doublet Aileron Deflections of Cessna 620 (Zoomed)	82

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Developed Computer Code in MATLAB Software	91

LIST OF ABBREVIATIONS

D_1	Denominator
AOA	Angle of Attack
CG	Center of Gravity
FLC	Fuzzy Logic Controller
LQR	Linear Quadratic Regulator
Num	Numerator
STFLC	Self-Tuning Fuzzy Logic Controller

LIST OF SYMBOLS

a	=	Aileron
AR	=	Aspect Ratio
b	=	Wingspan
c	=	Chord
C_{l_p}	=	The Variation of Rolling Moment Coefficient with Roll Rate.
C_{l_r}	=	The Variation of Rolling Moment Coefficient with Yaw Rate.
C_{l_β}	=	The Variation of Rolling Moment Coefficient with Sideslip Angle.
$C_{l_{\delta_A}}$	=	The Variation of Rolling Moment Coefficient with Aileron Deflection.
$C_{l_{\delta_R}}$	=	The Variation of Rolling Moment Coefficient with Rudder Deflection.
C_{n_p}	=	The Variation of Yawing Moment Coefficient with Roll Rate.
C_{n_r}	=	The Variation of Yawing Moment Coefficient with Yaw Rate.
$C_{n_T\beta}$	=	The Variation of Yawing Moment Coefficient with Thrust
C_{n_β}	=	The Variation of Yawing Moment Coefficient with Sideslip Angle.
$C_{n_{\delta_A}}$	=	The Variation of Yawing Moment Coefficient with Aileron Deflection.
$C_{n_{\delta_R}}$	=	The Variation of Yawing Moment Coefficient with Rudder Deflection.
C_{Y_p}	=	The Variation of Side Force Coefficient with Roll Rate.

C_{Y_r}	=	The Variation of Side Force Coefficient with Yaw Rate.
C_{Y_β}	=	The Variation of Side Force Coefficient with Sideslip Angle.
$C_{Y_{\delta_A}}$	=	The Variation of Side Force Coefficient with Aileron Deflection.
$C_{Y_{\delta_R}}$	=	The Variation of Side Force Coefficient with Rudder Deflection.
g	=	Acceleration of Gravity
h	=	Altitude
l	=	Characteristic Length
I_{XXB}	=	Moment of Inertia x-axis
I_{XZB}	=	Product of Inertia x and z-axis
I_{YYB}	=	Moment of Inertia y-axis
I_{ZZB}	=	Moment of Inertia z-axis
L	=	Sum of the Component of Moment in x axes
L_p	=	Rolling Moment with Roll Rate.
L_r	=	Rolling Moment with Yaw Rate.
L_β	=	Rolling Moment with Sideslip Angle.
L_{δ_A}	=	Rolling Moment with Aileron Deflection.
L_{δ_R}	=	Rolling Moment with Rudder Deflection.
M	=	Sum of the Component of Moment in y axes
M	=	Mach Number
m	=	Mass of Aircraft
N	=	Sum of the Component of Moment in z axes
N_r	=	Yawing Moment with Yaw Rate.
$N_T\beta$	=	Yawing Moment with Thrust

N_{β}	=	Yawing Moment with Sideslip Angle.
$N_{\delta A}$	=	Yawing Moment with Aileron Deflection.
$N_{\delta R}$	=	Yawing Moment with Rudder Deflection.
p	=	Component of Rotational Velocity about x axes
q	=	Component of Rotational Velocity about y axes
Q	=	Dynamic Pressure
q_1	=	Dynamic Pressure
r	=	Component of Rotational Velocity about z axes
S	=	Reference Area
u	=	Instantaneous Linear Velocity in x axes
U	=	Axial Velocity
U_1	=	Air Speed
v	=	Instantaneous Linear Velocity in y axes
v	=	Sideslip Velocity
V	=	Total Velocity Vector
w	=	Instantaneous Linear Velocity in z axes
X	=	Sum of the Component of Forces in x axes
x_{cg}	=	Location of CG-%MAC
Y	=	Sum of the Component of Forces in y axes
y	=	Length from Longitudinal Axis
Y_p	=	Side Force with Roll Rate.
Y_r	=	Side Force with Yaw Rate.
Y_{β}	=	Side Force with Sideslip Angle.

$Y_{\delta A}$	=	Side Force with Aileron Deflection.
$Y_{\delta R}$	=	Side Force with Rudder Deflection.
Z	=	Sum of the Component of Forces in z axes
β	=	Sideslip Angle
Γ	=	Dihedral Angle
C_l	=	Coefficient of Rolling Moment
$C_{L_{\text{Law}}}$	=	Coefficient of Lift due to Wing
C_m	=	Coefficient of Yawing Moment
C_n	=	Coefficient of Pitching Moment
C_x	=	Coefficient of Force in x axes
C_y	=	Coefficient of Force in y axes
C_z	=	Coefficient of Force in z axes
L_F	=	Lift Generated due to Fin
N_p	=	Yawing Moment with Roll Rate.
α	=	Angle of Attack
δ	=	Deflection
δ_A	=	Deflection of Aileron
τ	=	Taper Ratio
ψ	=	Yawing Angle
ϕ	=	Roll Angle

CHAPTER 1

INTRODUCTION

1.1 Background of Study

After the first flight made by Wilbur and Orville Wright in 1903, there was a rapid development in aeronautical and the progress and study made in the following decade was impressive. However, the flying qualities of their aircraft that time were always less than satisfactory due to the problems of stability and control. Many researchers like Bryan and Lanchester were studying the problems of stability and control at that time and they managed to come out with mathematical method to describe the flight dynamic and the general equations of motion of an aircraft with six degrees of freedom to describe the aircraft motion which it is in the same form as they are known today. (Anderson & Eberhardt, 2001)

Stability and control are study on how well an aircraft flies and how easily the aircraft can be controlled. Stability is the ability of an aircraft to return to a previous condition if it is upset by disturbance. The disturbance can be generated by the pilot' s action or atmospheric phenomena such as turbulence or a gust of air. An aircraft must have a good stability so that the pilot does not become tired by keep having to control the aircraft in order to make it stable. Whereas control is the ability to command the aircraft to perform a specific maneuver or to