



UNIVERSITI PUTRA MALAYSIA

**STABILITY AND CONTROL ASSESSMENT OF AN AERIAL TARGET
DRONE BASED ON A SCALE MODEL OF A-4 SKYHAWK JET
FIGHTER**

ABU ZAID BIN BAKAR

FK 2009 100



**STABILITY AND CONTROL ASSESSMENT
OF AN AERIAL TARGET DRONE BASED ON
A SCALE MODEL OF A-4 SKYHAWK JET
FIGHTER**

ABU ZAID BIN BAKAR

**Thesis Submitted to the School of Graduate
Studies, Universiti Putra Malaysia, in Fulfilment
of the Requirements for the Master of Science**

September 2009



DEDICATION

I praised to Allah the Almighty, given me the knowledge, effort and strength to complete this Master Degree. My respected mother, Madam Rakhiya Bee Binti Junoos, beloved wife Wan Noramelia Merican Binti Noorsa Merican, daughter, Nur Farhanah Zulaikha and new baby boy, Muhammad Faris.



ABSTRACT

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

STABILITY AND CONTROL ASSESSMENT OF AN AERIAL TARGET DRONE BASED ON A SCALE MODEL OF A-4 SKYHAWK JET FIGHTER

By

ABU ZAID BIN BAKAR

May 2009

Chairman : Abd Rahim Bin Abu Talib, Ph.D.

Faculty : Faculty of Engineering

A-4 Skyhawk is a jetfighter aircraft which was bought by our Royal Malaysia Air Force (RMAF) back in the year 1980s. The study is to evaluate the stability and control aspects of the design of A-4 Skyhawk as a target drone with a scale of one third. The condition of the studies involve the longitudinal and lateral controls of the open loop derivatives at the sea level and 10,000 feet altitude, for ranges of Mach number of 0.2, 0.3, 0.4, 0.5 and 0.6. Hence, the closed loop derivatives shall be designed to cater for the unsatisfactory parameters.

With the usage of stability software such as the United State Air Force Stability and Control DATCOM (USAF DATCOM), analysis softwares such as MATLAB and CATIA, the method of design concept shall be more viable in order to produce a stable design. The USAF DATCOM software is used to generate the static and dynamic aerodynamic derivatives of the given aircraft. MATLAB is mathematical software used



to perform high speed and massive calculations. MATLAB is used to obtain the transfer function of the aircraft equation of motion, to perform stability analysis and to plot the stability related graphs. The CATIA software is used to develop the full scale and scale size model of the A-4 Skyhawk jetfighter. From this software the scale model dimension, estimated weight and second moment of inertia is obtained. Thus, combination of all the software and calculation, the output of the study shall be able to meet the objectives of the study.

It was found that, for the open loop derivatives of the longitudinal motion, the flying qualities for both short period and phugoid modes felt in the Level 2 category. As for the lateral motion, the flying qualities of the Dutch roll, spiral and roll modes felt in the Level 1 category as described by the Cooper-Harper scale.

However, the critical scenario for the longitudinal and lateral for both the sea level and 10,000 feet altitude occurred at the speed of Mach number 0.2, where it had the most oscillatory conditions and the least settle for steady state condition. This may due to the less effectiveness of the delta wing at low speed flying condition.

ABSTRAK

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENILAIAN DALAM KESTABILAN DAN MENGAWAL KAPAL TERBANG SASARAN BERDASARKAN DARIPADA SKALA MODEL JET PEJUANG A-4 SKYHAWK

Oleh

ABU ZAID BIN BAKAR

Mei 2009

Pengerusi : Abd Rahim Bin Abu Talib, Ph.D.

Fakulti : Fakulti Kejuruteraan

A-4 Skyhawk merupakan pesawat jetpejuang yang telah dibeli oleh Tentera Udara Di Raja Malaysia dalam tahun 1980an. Kajian ini dibuat adalah untuk menyelidiki tahap stabiliti rekabentuk pesawat A-4 Skyhawk sebagai pesawat sasaran dengan dikesilkan sebanyak 1/3 daripada bentuk asal. Kajian ini meliputi keadaan pesawat dari segi menegak dan juga melintang di dalam situasi kawalan terbuka, pada ketinggian paras laut dan ketinggian 10,000 kaki dari paras laut, dan merangkumi kelajuan nombor Mach 0.2, 0.3, 0.4, 0.5 dan 0.6. Setelah itu, kawalan tertutup akan direka untuk mengatasi situasi yang kritikal yang dihadapi oleh pesawat ini.

Dengan menggunakan peralatan sistem komputer stabiliti seperti United State Air Force Stability and Control DATCOM (USAF DATCOM), peralatan analisis seperti MATLAB dan peralatan komputer rekapipta seperti CATIA, cara-cara untuk mendapatkan konsep rekapipta pesawat adalah didapati lebih berkesan bagi

merekabentuk sebuah pesawat yang stabil. Sistem USAF DATCOM digunakan untuk mendapatkan bacaan aerodinamik bagi keadaan statik dan dinamik untuk sesebuah pesawat itu. MATLAB adalah penganalisa matematik bagi tujuan pengiraan yang pantas dan banyak. MATLAB digunakan bagi tujuan mendapatkan fungsi pengubahan bagi persamaan bagi pergerakan pesawat, untuk menganalisa stabiliti dan untuk melakarkan graf stabiliti yang berkenaan. Sistem CATIA pula digunakan untuk melakarkan model skala penuh dan skala tertentu bagi pesawat jetpejuang A-4 Skyhawk. Melalui CATIA, dimensi model berskala, anggaran berat pesawat serta inersia tahap kedua dapat diperolehi. Oleh yang demikian, dengan penggabuan sistem komputer dan pengiraan yang dinyatakan, hasilnya didapati boleh memenuhi matlamat penyelidikan ini.

Hasil kajian didapati bahawa, bagi situasi kawalan terbuka untuk sudut melintang, kualiti penerbangan bagi kedua-dua jangka pendek dan jangka panjang adalah di dalam kategori peringkat kedua. Manakala untuk sudut membujur pula, kesemua kualiti penerbangan adalah di dalam kategori peringkat pertama mengikut skala Cooper-Harper.

Walaupun, situasi yang kritikal yang dihadapi oleh pesawat ini bagi posisi melintang dan membujur untuk ketinggian paras laut dan 10,000 kaki dari paras laut adalah pada kelajuan 0.2 nombor Mach, dimana ia mempunyai tahap pergerakan yang berulang-ulang serta ia juga mengambil masa yang paling lama untuk stabil. Ini mungkin berpunca daripada kurang efektifnya sayap berbentuk delta bagi penerbangan pada kelajuan yang rendah.

ACKNOWLEDGEMENTS

In the name of ALLAH S.W.T., The Most Beneficial and The Most Benevolent. Glory to ALLAH S.W.T. and asking blessing on salute noble Prophet Muhammad S.A.W., his companion's and who those follow him upholding the cause of right path. The author thank to ALLAH S.W.T by He's infinite Mercy and Grace, made him humble endeavors possible and this blessing upon thought of the completing of this thesis.

The author extends his gratitude to Dr. Abd Rahim Abu Talib and Lieutenant Colonel (R) Mohamed Tarmizi Ahmad, for their guidance, generous support and without their knowledge, perceptiveness and cracking-of-the-whip the author would never have finished the thesis. The authors also appreciated the helped from his colleagues, Mr. Hafizi, Mr. Husri, Mr. Wan Adlan, Mr. Rizal, Mr. Abdul Malek, Mr. Zulkifli, Mr. Shahrul Ahmad Shah, the Dean of UniKL MIAT, Professor Ahmad Zahir, for his never ending encouragement, Dr. Rini Akmeliawati, for her superb MATLAB knowledge and Mr. Singgih Satrio Wibowo for his contribution towards the author's success.

Finally and most importantly are the author's family, particularly his parents, wife, Wan Noramelia Merican, who had putting with his late hours, spoiled weekends, also his daughter, Nur Farhanah Zulaikha and his new baby boy, Muhammad Faris who have been and will be his inspiration.



I certify that a Thesis Examination Committee has met on 17 September 2009 to conduct the final examination of Abu Zaid Bin Bakar on his thesis entitled “Stability and Control Assessment of an Aerial Target Drone Based on Scaled Model of A-4 Skyhawk Jet Fighter” 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 Master of Science.

Members of the Thesis Examination Committee were as follows:

Colonel (R) Mohd Ramly Mohd Ajir, M.Sc.

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Ir. –Ing. Renuganth A/L Varatharajoo, Ph.D.

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Major (R) Ir. Mohd Saleh Yahaya, M.Sc.

Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Shuhaimi Mansor, Ph.D.

Associate Professor
Faculty of Mechanical Engineering
Universiti Teknologi Malaysia
(External Examiner)

BUJANG BIN KIM HUAT, Ph.D.

Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 24 December 2009



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

Abd Rahim Abu Talib, Ph.D.

Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Lt. Col. (R) Mohamed Tarmizi Ahmad, M.Sc.

Faculty of Engineering
Universiti Putra Malaysia
(Member)

HASANAH MOHD GHAZALI, PhD

Professor / Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 14 January 2010



DECLARATION

I declare that the thesis is based on my original work except for quotations and citations which have been dully acknowledged. I also declare that it has not been previously or is not concurrently, submitted for any other degree at UPM or other institutions.

ABU ZAID BIN BAKAR

11 February 2010

TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ASBTRAK	v
ACKNOWLEDGEMENTS	vii
APPROVAL	viii
DECLARATION	x
LIST OF TABLES	xiii
LIST OF FIGURES	xv
LIST OF ABBREVIATIONS	xx
CHAPTER	
1 INTRODUCTION	1
1.1 Preface	1
1.2 Problem Statements	8
1.3 Hypothesis	9
1.4 Research Objectives	10
1.5 Thesis Organization	10
2 LITERATURE REVIEW	11
2.1 Preface	11
2.2 Preliminary Analysis	13
2.3 Primary Mission	17
2.4 Technical Requirements	18
2.5 Skyhawk A-4	21
2.6 Scaled Skyhawk A-4	24
2.7 Static and Dynamic Stability Control	25
2.8 State Space Equation	27
2.9 Open Loop and Closed Loop Analysis	34
2.10 Root Locus Technique	37
2.11 United State Air Force Stability and Control DATCOM	43
2.11.1 Addressable Configuration	44
2.11.2 Static and Dynamic Stability Characteristic	46
2.11.3 Operational Limitation	49
2.12 MATLAB	50
2.13 Summary	51



3	METHODOLOGY	52
3.1	Preface	52
3.2	Aircraft Modeling	54
3.2.1	Moment of Inertia	55
3.2.2	Scaled Model	56
3.3	Flight Conditions	57
3.4	Aerodynamic Derivatives	58
3.4.1	USAF Stability and Control DATCOM	60
3.4.2	Validation of the Aerodynamics Data	61
3.5	Scaled (1/3) Skyhawk A-4 Equation of Motion	61
3.6	Stability Analysis	62
3.6.1	Open Loop	62
3.6.2	Closed Loop	63
4	RESULTS AND DISCUSSION	70
4.1	Preface	70
4.2	Validation of aerodynamics data from USAF DATCOM	70
4.3	Scaled A-4 Skyhawk Configuration	78
4.4	Moment of Inertia	80
4.5	Aerodynamics Derivatives	81
4.6	Open Loop Results	85
4.6.1	Longitudinal Derivatives of A-4 Skyhawk	85
4.6.1.1	Sea Level	85
4.6.1.2	10,000 feet altitude	90
4.6.2	Lateral Derivatives of A-4 Skyhawk	95
4.6.2.1	Sea Level	95
4.6.2.2	10,000 feet altitude	100
4.6.3	Open Loop Critical Case	105
4.7	Closed Loop Results	105
4.7.1	Longitudinal Directional of A-4 Skyhawk	107
4.7.1.1	Sea Level	107
4.7.1.2	10,000 feet altitude	110
4.7.2	Lateral Directional of A-4 Skyhawk	113
4.7.2.1	Sea Level	114
4.7.2.2	10,000 feet altitude	121
5	CONCLUSION AND RECOMMENDATION	130
5.1	Summary and General Conclusion	130
5.2	Recommendation for Future Research	131
	REFERENCES	133
	APPENDIX A: USAF DATCOM DATA (CD ROM)	137
	APPENDIX B: STATIC AND DYNAMIC DERIVATIVES OBTAINED FROM DATCOM	138
	APPENDIX C: USAF DATCOM INPUT COMMAND	145
	BIODATA OF THE STUDENT	149



LIST OF TABLES

Table		Page
2.1	Unmanned Target Drones Configuration	14
2.2	Requirement from Royal Malaysian Army	18
2.3	Specification of A-4 Skyhawk Full Scaled	23
2.4	Estimation of Second Moment of Inertia for Scaled A-4 Skyhawk	25
2.5	Summary of Kinematics and Dynamics Equation of Motions	29
2.6	Classification of airplanes	42
2.7	Flight phase categories	42
2.8	Flying Qualities	43
2.9	Addressable Configurations	45
2.10	Static Stability Characteristic Output as a Function of Vehicle Configuration and Speed Regime	47
2.11	Dynamic Stability Characteristic Output as a Function of Vehicle	48
3.1	Longitudinal-Directional Flight Conditions	57
3.2	Lateral-Directional Flight Conditions	57
3.3	Summary of Longitudinal Derivatives	59
3.4	Summary of Lateral Derivatives	59
4.1	Comparison of derivatives for USAF DATCOM and Nelson for the full scale of A-4 Skyhawk for the Sea Level Condition	71
4.2	Comparison of Longitudinal Derivatives for the Sea Level Conditions for USAF DATCOM and Nelson	72
4.3	Comparison of Lateral Derivatives for the Sea Level Conditions for USAF DATCOM and Nelson	73
4.4	Detail Configuration of Scaled A-4 Skyhawk Target Drones	79



4.5	Estimation of Mass, Area, Volume and Centre of Gravity for the Target Drone	80
4.6	Estimation of Moment of Inertia for the Target Drone	81
4.7	Summary of Roots, Period, Half Cycle, Half Amplitude and Damping Ratio for Longitudinal Motion at the Sea Level	83
4.8	Summary of Roots, Period, Half Cycle, Half Amplitude and Damping Ratio for Longitudinal Motion at 10,000 feet altitude	83
4.9	Summary of Roots, Period, Half Cycle, Half Amplitude and Damping Ratio for Lateral Motion at the Sea Level	84
4.10	Summary of Roots, Period, Half Cycle, Half Amplitude and Damping Ratio for Lateral Motion at 10,000 feet altitude	84



LIST OF FIGURES

Figure		Page
1.1	Ground Control Station (GCS)	5
2.1	(A), (B), (C) Examples of Target Drones	12
2.2	Chart of Aircraft Configuration Variations	15
2.3	A-4PTM Skyhawk	21
2.4	Scaled Design of A-4 Skyhawk	24
2.5	Static Stability	26
2.6	Example of Stable and Unstable Dynamic Motions	27
2.7	Mathematical Diagram of an Aircraft Control	30
2.8	Mathematical Diagram of Sensor System	32
2.9	Open-Loop Control System	34
2.10	Closed-Loop Control System	35
2.11	Root Locus of Lateral-Directional Motion in s-plane	38
2.12	Root Locus of Longitudinal-Directional Motion in s-plane	39
2.13	Phugoid	40
2.14	Pitch Oscillation	40
2.15	Damping Ratio	41
3.1	Flow Chart of Research Methodology	54
3.2	Scaled (1/3) Model of A-4 Skyhawk	55
3.3	Open-Loop Schematic System	62
3.4	Closed-Loop Schematic Diagram	64
3.5	Closed-Loop Simulink Diagram	65



4.1	Comparison of Step Response between USAF DATCOM and Nelson for Longitudinal Motion at 0.4 Mach for the sea level	75
4.2	Comparison of Step Response between USAF DATCOM and Nelson for Lateral Motion at 0.4 Mach for the sea level	75
4.3	Comparison of Step Response between USAF DATCOM and Nelson for Longitudinal Motion at 0.5 Mach for the sea level	76
4.4	Comparison of Step Response between USAF DATCOM and Nelson for Lateral Motion at 0.5 Mach for the sea level	76
4.5	Comparison of Step Response between USAF DATCOM and Nelson for Longitudinal Motion at 0.6 Mach for the sea level	77
4.6	Comparison of Step Response between USAF DATCOM and Nelson for Lateral Motion at 0.6 Mach for the sea level	77
4.7	Target Drone Isometric View	78
4.8	Target Drone Drawing	78
4.9	Target Drone Moment of Inertia Components	80
4.10	Step Response of Longitudinal at the Sea Level for u for various speeds	86
4.11	Step Response of Longitudinal at the Sea Level for w for various speeds	86
4.12	Step Response of Longitudinal at the Sea Level for q for various speeds	87
4.12A	Step Response of Longitudinal at the Sea Level for q for various speeds for time from 0 to 30 seconds	87
4.13	Step Response of Longitudinal at the Sea Level for θ for various speeds	88
4.14	Impulse Response of Longitudinal at the Sea Level for u for various speeds	88
4.15	Impulse Response of Longitudinal at the Sea Level for w for various speeds	89
4.16	Impulse Response of Longitudinal at the Sea Level for q for	89



	various speeds	
4.17	Impulse Response of Longitudinal at the Sea Level for θ for various speeds	90
4.18	Step Response of Longitudinal at 10,000 feet for u for various speeds	91
4.19	Step Response of Longitudinal at 10,000 feet for w for various speeds	91
4.20	Step Response of Longitudinal at 10,000 feet for q for various speeds	92
4.21	Step Response of Longitudinal at 10,000 feet for θ various speeds	92
4.22	Impulse Response of Longitudinal at 10,000 feet for u for various speeds	93
4.23	Impulse Response of Longitudinal at 10,000 feet for w for various speeds	93
4.24	Impulse Response of Longitudinal at 10,000 feet for q for various speeds	94
4.25	Impulse Response of Longitudinal at 10,000 feet for θ for various speeds	94
4.26	Step Response of Lateral at the Sea Level for β for various speeds	96
4.27	Step Response of Lateral at the Sea Level for p for various speeds	96
4.28	Step Response of Lateral at the Sea Level for r for various speeds	97
4.29	Step Response of Lateral at the Sea Level for φ for various speeds	97
4.30	Impulse Response of Lateral at the Sea Level for β for various speeds	98
4.31	Impulse Response of Lateral at the Sea Level for p for various speeds	98
4.32	Impulse Response of Lateral at the Sea Level for r for various speeds	99
4.33	Impulse Response of Lateral at the Sea Level for φ for various speeds	99



	various speeds	
4.34	Step Response of Lateral at 10,000 feet for β for various speeds	101
4.35	Step Response of Lateral at 10,000 feet for p for various speeds	101
4.36	Step Response of Lateral at 10,000 feet for r for various speeds	102
4.37	Step Response of Lateral at 10,000 feet for φ for various speeds	102
4.38	Impulse Response of Lateral at 10,000 feet for β for various speeds	103
4.39	Impulse Response of Lateral at 10,000 feet for p for various speeds	103
4.40	Impulse Response of Lateral at 10,000 feet for r for various speeds	104
4.41	Impulse Response of Lateral at 10,000 feet for φ for various speeds	104
4.42	Simulink Diagram for Closed-Loop	105
4.43	Comparison of Closed Loop and Open Loop for u output of Mach number 0.2 at the Sea Level	106
4.44	Comparison of Closed Loop and Open Loop for w output of Mach number 0.2 at the Sea Level	107
4.45	Comparison of Closed Loop and Open Loop for q output of Mach number 0.2 at the Sea Level	108
4.46	Comparison of Closed Loop and Open Loop for θ output of Mach number 0.2 at the Sea Level	109
4.47	Comparison of Closed Loop and Open Loop for u output of Mach number 0.2 at 10,000 feet altitude	110
4.48	Comparison of Closed Loop and Open Loop for w output of Mach number 0.2 at 10,000 feet altitude	111
4.49	Comparison of Closed Loop and Open Loop for q output of Mach number 0.2 at 10,000 feet altitude	112
4.50	Comparison of Closed Loop and Open Loop for θ output of Mach number 0.2 at 10,000 feet altitude	113
4.51	Comparison of Closed Loop and Open Loop for β output of Mach number 0.2 at the Sea Level	114



4.52	Comparison of Closed Loop and Open Loop for p output of Mach number 0.2 at the Sea Level	115
4.53	Comparison of Closed Loop and Open Loop for r output of Mach number 0.2 at the Sea Level	116
4.54	Comparison of Closed Loop and Open Loop for φ output of Mach number 0.2 at the Sea Level	117
4.55	Comparison of Closed Loop and Open Loop for β output of Mach number 0.6 at the Sea Level	118
4.56	Comparison of Closed Loop and Open Loop for p output of Mach number 0.6 at the Sea Level	119
4.57	Comparison of Closed Loop and Open Loop for r output of Mach number 0.6 at the Sea Level	120
4.58	Comparison of Closed Loop and Open Loop for φ output of Mach number 0.6 at the Sea Level	121
4.59	Comparison of Closed Loop and Open Loop for β output of Mach number 0.2 at 10,000 feet altitude	122
4.60	Comparison of Closed Loop and Open Loop for p output of Mach number 0.2 at 10,000 feet altitude	123
4.61	Comparison of Closed Loop and Open Loop for r output of Mach number 0.2 at 10,000 feet altitude	124
4.62	Comparison of Closed Loop and Open Loop for φ output of Mach number 0.2 at 10,000 feet altitude	125
4.63	Comparison of Closed Loop and Open Loop for β output of Mach number 0.6 at 10,000 feet altitude	126
4.64	Comparison of Closed Loop and Open Loop for p output of Mach number 0.6 at 10,000 feet altitude	127
4.65	Comparison of Closed Loop and Open Loop for r output of Mach number 0.6 at 10,000 feet altitude	128
4.66	Comparison of Closed Loop and Open Loop for φ output of Mach number 0.6 at 10,000 feet altitude	129



LIST OF ABBREVIATIONS

List		Page
M_u	Pitching moment due to velocity in x-direction	24
M_q	Pitching moment due to pitch rate	24
M_w	Pitching moment due to velocity in z-direction	24
M_{δ_e}	Pitching moment due to change in elevator	24
$M_{\dot{w}}$	Pitching moment due to change in velocity in z-direction	24
N_β	Yawing moment due to sideslip angle	25
L_β	Rolling moment due to sideslip angle	25
N_p	Yawing moment due to roll rate	25
L_p	Rolling moment due to roll rate	25
N_r	Yawing moment due to yaw rate	25
L_r	Rolling moment due to yaw rate	25
N_{δ_a}	Yawing moment due to change in aileron deflection	25
N_{δ_r}	Yawing moment due to change in rudder deflection	25
L_{δ_a}	Rolling moment due to change in aileron deflection	25
L_{δ_r}	Rolling moment due to change in rudder deflection	25
I_x	Second moment of inertia in x-direction	25
I_y	Second moment of inertia in y-direction	25
I_z	Second moment of inertia in z-direction	25



ΣF	Summation of all external forces acting on a body	29
$\frac{d}{dt}(mV)$	Time rate of change of the momentum of the body	29
ΣM	Summation of the external moment acting on the body	29
$\frac{dH}{dt}$	Time rate of change of the moment of momentum	29
X_u	Axial force due to velocity component in x-direction	32
X_w	Axial force due to velocity component in z-direction	32
g	Gravitational acceleration	32
Z_u	Normal force due to velocity component in x-direction	32
Z_w	Normal force due to velocity component in z-direction	32
u_0	Reference velocity component in x-direction	32
$\Delta \dot{x}$	Rate of change in velocity component in x-direction	32
$\Delta \dot{w}$	Rate of change in velocity component in z-direction	32
$\Delta \dot{\theta}$	Rate of change in pitching angle	32
$\Delta \dot{q}$	Rate of change in pitch with respect to time	32
X_{δ_e}	Axial force due to change in elevator angle	32
X_{δ_r}	Axial force due to change in throttle setting	32
Z_{δ_e}	Normal force due to change in elevator angle	32
Z_{δ_r}	Normal force due to change in throttle setting	32
Δ	Increment of parameter	32
δ_e	Elevator angle	32

δ_T	Throttle setting	32
η	Control vector	32
x	State vector	32
Y_β	Side force due to side slip rate	34
Y_r	Side force due to yaw rate	34
Y_p	Side force due to roll rate	34
Y_{δ_r}	Side force due to change in rudder deflection	34
β	Side slip angle	35
p	Roll rate	35
r	Yaw rate	35
ϕ	Bank angle	35
δ_a	Aileron deflection	35
δ_r	Rudder deflection	35
ζ	Damping ratio	38
C_D	Drag coefficient	45
C_L	Lift coefficient	45
C_M	Coefficient of pitching moment	45
C_N	Coefficient of yawing moment	45
C_A	Coefficient of axial force	45
C_{L_α}	Variation of aircraft lift coefficient with angle of attack	45
C_{m_α}	Variation of aircraft pitching moment coefficient with angle of attack	45



$C_{Y\beta}$	Variation of aircraft side slip force coefficient with roll rate	45
$C_{n\beta}$	Variation of aircraft yawing moment coefficient with side slip angle	45
$C_{l\beta}$	Variation of aircraft rolling moment coefficient with side slip angle	45
C_{lq}	Variation of aircraft rolling moment coefficient with pitch rate	45
C_{Mq}	Variation of aircraft pitching moment coefficient with pitch rate	45
$C_{L\alpha}$	Variation of aircraft lift coefficient with angle of attack	45
$C_{m\alpha}$	Variation of aircraft pitching moment coefficient with angle of attack	45
C_{lp}	Variation of aircraft rolling moment coefficient with roll rate	45
C_{Yp}	Variation of aircraft side force coefficient with roll rate	45
C_{np}	Variation of aircraft yawing moment coefficient with roll rate	45
C_n	Coefficient of yawing moment	45
C_l	Coefficient of rolling moment	45
Q	Flight dynamic pressure	58
S	Wing area	58
\bar{c}	Mean geometric chord	58
b	Wing span	58



CHAPTER 1

INTRODUCTION

1.1 Preface

Aircraft design is an intellectual engineering process of creating on paper or on computer a flying machine to meet certain specifications and requirements established by potential users. It is also use to develop new idea and technology (Raymer, 1999).

In Malaysia, aircraft design is still a new field yet to be ventured since it has not been taken seriously. Malaysia has produced two-seater light aircrafts, which are Eagle Aircraft (CTRM, 2007) and MD 3 (Prakash, 2000). These projects were only concerned only on the manufacturing stage, but not the designing stage. In order to improve the design ability in aerospace industry, Malaysian aerospace industries should be involved in designing aircrafts. By doing so, it will expose the local engineers and technicians to the every aspect of the aircraft design.

Most of the modern fighter aircraft designs are shifting from the naturally stable airframe towards sophisticated flight control systems. The advent of highly-augmented flight control systems has decreased the accuracy with which the static and dynamic derivatives must be known in preliminary design. Furthermore, significant errors in the estimation of the static and dynamic derivatives can result in

