UNIVERSITI PUTRA MALAYSIA

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

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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

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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

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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 dikecilkan 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 rekacipta seperti CATIA, cara-cara untuk mendapatkan konsep rekacipta 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 penggabuhan sistem kompoter 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.

Walaubagaimanapun, 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.

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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.

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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.

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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

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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_T}	Axial force due to change in throttle setting	32
Z_{δ_e}	Normal force due to change in elevator angle	32
Z_{δ_T}	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
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Y_r	Side force due to yaw rate	34
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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_β}	Variation of aircraft side slip force coefficient with roll rate	45
C_{n_β}	Variation of aircraft yawing moment coefficient with side slip angle	45
C_{l_β}	Variation of aircraft rolling moment coefficient with side slip angle	45
C_{l_q}	Variation of aircraft rolling moment coefficient with pitch rate	45
C_{M_q}	Variation of aircraft pitching moment coefficient with pitch rate	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_{l_p}	Variation of aircraft rolling moment coefficient with roll rate	45
C_{Y_p}	Variation of aircraft side force coefficient with roll rate	45
C_{n_p}	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
$\overline{c}$	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