THE ANALYSIS OF WING PERFORMANCE FOR RECONNAISSANCE UAV

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The Analysis of Wing Performance for Reconnaissance UAV

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Report submitted in partial fulfillment of the
requirements for the award of the degree of
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We certify that the project entitled “The Analysis of Wing Performance for Reconnaissance UAV” is written by Zulkifli bin Yusof. We have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. We herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering.

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TABLE OF CONTENTS

	Page
PANEL'S DECLARATION	ii
SUPERVISOR'S DECLARATION	iii
STUDENT'S DECLARATION	iv
ACKNOWLEDGEMENTS	v
ABSTRACT	vii
ABSTRAK	viii
TABLE OF CONTENTS	ix
LIST OF TABLES	xiii
LIST OF FIGURES	xiv
LIST OF ABBREVIATIONS	xvi
LIST OF SYMBOLS	xvii
LIST OF SUBSCRIPTS	xix

CHAPTER 1 INTRODUCTION

1.1	Project Background	1
1.2	Project Objective	2
1.3	Project Scopes	2
1.4	Problem Statements	3
1.5	Project Assumptions	3
1.6	Technical Task Requirements	4
	1.6.1 Introduction	4
	1.6.2 Standard Requirement	5
	1.6.3 Performance Parameters	5
	1.6.4 Technical Level of Aircraft	7
	1.6.5 Economical Parameters	8
	1.6.6 Power Plant Requirement	8
	1.6.7 Main System Parameter Requirements	9
	1.6.8 Reliability and Maintainability	9
	1.6.9 Unification Level	9

1.7 Mission Profile 10

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction 11
2.2 History of Unmanned Aerial Vehicle (UAV) 12
2.3 Aircraft Design Textbooks and Researches 13
2.3.1 Morphing Wing HALE UAV 13
2.3.2 Design, Development and Manufacture of a Search and Rescue Unmanned Aerial Vehicle 13
2.3.3 Coastal Watch UAV 14
2.3.4 Roskam's Aircraft Design Series 14
2.3.5 Aircraft Performance and Design 14
2.4 Current UAV Types and Design 15
2.5 Wing Design and Configuration 17
2.6 Airfoil Shape 20
2.7 The UAV Powerplant 21
2.8 Camera for Reconnaissance 22

CHAPTER 3 RESEARCH METHODOLOGY

3.1 Introduction 23
3.2 Flow Chart 24
3.3 Conceptual Design 27
3.3.1 Weight Estimation 27
3.3.2 Fuel Weight (W_f) Calculation 28
3.3.3 Aircraft Sizing 31
3.3.4 Drag Polar 31
3.3.5 FAR 23 Sizing 32
3.4 Software 34
3.4.1 SolidWorks 34
3.4.2 XFLR5 34
3.4.3 DesignFoil 35
3.4.4 Profili 35

3.5 Preliminary Sketches 35

CHAPTER 4 RESULTS AND DISCUSSIONS

4.1 Introduction 36
4.2 Matching Diagram 37
4.3 Airfoil Design Selection 38
4.3.1 Detailed Airfoil Requirement 38
4.3.2 NACA Airfoil Potential Candidates 39
4.3.3 Three Dimensional Effect 39
4.3.3 Two Dimensional Analysis 40
4.3.4 Airfoil Selection Process 42
4.4 Wing Profile Design 44
4.5 Mean Aerodynamic Chord Analysis 46
4.6 Three Dimensional Lift, $C_{L\ max}$ 49
4.7 Weight Distribution Analysis 49
4.8 Wing Simulation Analysis 51
4.9 CAD Design 52
4.9.1 Wing 3D Design 53
4.9.2 Full Body UAV 3D Design 54
4.10 Summarized Results 56
4.11 Discussions 57

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions 61
5.2 Recommendations 62

REFERENCES 63
APPENDICES 65
A1 Gantt chart for FYP 1 65
A2 Gantt chart for FYP 2 66

A3	Flow Chart for Overall Project	67
B1	Engine Technical Data	68
B2	Camera Specification List	69
B3	Conceptual Design Calculation	70
B4	NACA Analysis Table	79
B5	NACA Plotted Data Analysis	81
B6	NACA Selected Profile	83
B7	NACA 6311 Analysis	85
B8	Mean Aerodynamic Chord Calculations	86
B9	Three Dimensional Lift Calculations	89
B10	Weight Distribution Calculations	90
B11	XFLR5 Wing Simulation Analysis	92
C1	Preliminary Sketches	94
C2	CAD Design (Wing)	97
C3	CAD Design (UAV Full body)	100

LIST OF TABLES

Table No.		Page
2.1	Technical UAV data	16
2.2	Engine data	21
2.3	Camera technical data	22
3.1	Fuel Weight Division from Specified Mission Profile	29
3.2	Assumptions Properties	31
4.1	NACA Airfoil Analysis at Re = 1.0×10^5	39
4.2	NACA Airfoil Analysis at Re = 6.0×10^5	40
4.3	Weight balance to W_{TO}	50
4.4	Summarized Results	56

LIST OF FIGURES

Figure No.		Page
1.1	Mission Profile	10
2.1	Swept wing	17
2.2	Straight wing	17
2.3	Delta wing	18
2.4	Position of wing on aircraft	18
2.5	Wing notations	19
2.6	NACA nomenclature	20
2.7	Airfoil notation	20
2.8	RCV60-SP engine	21
2.9	FlyCamOne 2 camera	22
3.1	Flow chart for overall FYP	24
3.2	Technology Diagram	28
3.3	Graph $W_{e,\ tent}$ and $W_{e,\ all}$ Vs W_{TO}	30
4.1	Matching Diagram	37
4.2	Graph C_l Vs C_d	41
4.3	Graph C_l Vs Alpha and C_d Vs Alpha	41
4.4	Graph C_l/C_d Vs Alpha and C_m Vs Alpha	42
4.5	NACA 6311 profile	42
4.6	Graph C_l Vs Alpha for NACA 6311 airfoil at 1.0×10^5	43
4.7	Graph C_l Vs Alpha for NACA 6311 airfoil at 6.0×10^5	43
4.8	Effect of taper ratio on lift distribution	44

4.9	Mid plane configuration	45
4.10	Parameter of half span wing	46
4.11	MAC for wing with $\lambda = 0.5$	48
4.12	Location of wing to the fuselage	48
4.13	XFLR5 simulation	51
4.14	Graph $C_{L\ wing}$ Vs Alpha	52
4.15	Half span wing profile	53
4.16	Wing profile top view	53
4.17	3D view of finish UAV model	54
4.18	Exploded view of UAV	55

LIST OF ABBREVIATIONS

2D	Two Dimensional
3D	Three Dimensional
AOA	Angle of Attack
ARCAA	Australian Research Centre for Aerospace Automation
CAD	Computer Aided Design
CFD	Computational Fluid Dynamics
FAR	Federal Air Regulation
FPASS	Force Protection Aerial Surveillance System
HALE	High Altitude Long Endurance
MAC	Mean Aerodynamic Chord
MAV	Micro Air Vehicle
NACA	National Advisory Committee for Aeronautics
UAV	Unmanned Aerial Vehicle
USN	United States Navy
WWI	World War 1
WWII	World War 2

LIST OF SYMBOLS

α	Angle of attack
η_p	Propeller efficiency
π	Product, or 3.142
ρ	Air density
σ	Air density ratio
λ	Tapered ratio
A	Aspect ratio
a, b	Regression line constants defined by Equation 3.21, Roskam (2005)
A, B	Regression line constants defined by Equation 2.16, Roskam (2005)
c, d	Regression line constants defined by Equation 3.22, Roskam (2005)
C	Chord length
C_D	Drag coefficient
$C_{D\,o}$	Drag Polar
CGR	Climb gradient, defined by Equation 3.28, Roskam (2005)
CGRP	Climb gradient parameter, defined by Equation 3.30, Roskam (2005)
C_L	Lift coefficient
C_m	Pitching moment coefficient
D	Drag

e	Oswald's efficiency factor
E	Endurance
f	Equivalent parasite area
FAR	Federal Air Regulation
h	Altitude
I_p	Power index, Equation 3.51, Roskam (2005)
L	Lift
L/D	Lift-to-drag ratio
M_{ff}	Mission fuel fraction
P	Power
R	Range
RC	Rate of climb
RCP	Rate of climb parameter, Equation 3.24 and 3.25, Roskam (2005)
Re	Reynolds Number
s	Distance, used in take-off and landing equations with subscripts
S	Wing area
S_{wet}	Wetted area
t	Time
V	True airspeed
W	weight

LIST OF SUBSCRIPTS

cl	Climb
cr	Cruise
E	Empty
ff	Fuel fraction
F	Mission fuel
h	Altitude
INS	Vehicle instrumentation
L	Landing
ltr	Loiter
max	Maximum
OE	Operating empty
PL	Payload
PROP	Propulsion
RC	Rate of climb
r	Root
s	Stall
ST	Vehicle Structure
TO	Take-off
t	Tip
tent	Tentative

tfo	Trapped fuel and oil
used	Used (fuel)
w	Wing

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ABSTRACT

Through decade, the needs of the aircraft technologies are quite demanding and most of the demands came from the military and civil. The need of the technologies in nowadays life has evolving it into various types of shapes and design according to each task of work that needs to be handled. The aircraft can be classified into two common types, which are manned aircraft and unmanned aircraft. The unmanned aircraft is commonly known as the unmanned aerial vehicle or UAV. The purpose of UAV is to assist and complete the work that human cannot handle such as the bushfire surveillance. In this thesis, a mini UAV that capable to assist the work of reconnaissance and surveillance was designed and developed. The UAV should be able to complete certain parameters that already decided before the project was conducted. The main criterion of this UAV as to assist the given task is to have a perfect performance, which is having a smooth flight operation. To achieve the smooth flight operation, the main concern is to have perfect wing configuration. Therefore, the focus and purpose of this project is to analyze and choose the suitable wing parameters for the mini UAV. As the project develops, the UAV should have a 2 m wing span, 1.2 m fuselage length and 3.8 kg takeoff weight. It is quite light and easy to lost control. To avoid this problem, it is important to calculate where to put the wing onto the fuselage and which airfoil should be used for the wing. If the selection are made carelessly, the UAV probably cannot fly or can fly but in a bad condition. The analysis of the wing parameters was made using certain software that capable to act as the virtual wind tunnel. The best selection of the wing will be modeled using the CAD program as the final results of this project.

ABSTRAK

Semenjak berdekad lalu, permintaan terhadap teknologi pesawat penerbangan telah meningkat dan kebanyakan permintaan hadir daripada orang awam dan pihak angkatan tentera. Keperluan terhadap teknologi ini di dalam kehidupan seharian telah mengubah ia kepada pelbagai bentuk dan saiz bergantung kepada tugasan yang perlu dilakukan. Pesawat penerbangan boleh diklasifikasikan terhadap dua jenis iaitu pesawat dengan pemandu dan pesawat tanpa pemandu. Secara amnya, pesawat tanpa pemandu lebih dikenali sebagai kenderaan kawalan tanpa pemandu atau UAV. Tujuan utama UAV adalah untuk membantu dan menyudahkan tugasan yang tidak dapat diselesaikan oleh manusia seperti pengawasan kebakaran hutan. Di dalam tesis ini, sebuah UAV mini yang berkebolehan untuk membantu tugasan pengintipan dan pengawasan telah direka dan dibangunkan. UAV ini seharusnya berkebolehan untuk menyudahkan sesetengah parameter yang telah ditetapkan sebelum projek ini dijalankan. Kriteria utama UAV ini dalam membantu menyudahkan tugasan yang diberikan adalah dengan mempunyai prestasi yang sempurna iaitu dengan mempunyai operasi penerbangan yang lancar. Untuk mencapai tahap operasi penerbangan yang lancar, keutamaan yang perlu dititikberatkan adalah dengan mempunyai konfigurasi sayap yang sempurna. Oleh itu, fokus dan tujuan projek ini dijalankan adalah untuk menganalisa dan memilih parameter sayap yang bersesuaian dengan UAV mini ini. Sepanjang projek ini berjalan, UAV ini seharusnya mempunyai 2 m panjang sayap, 1.2 m panjang rangka pesawat dan berat pesawat berlepas adalah sebanyak 3.8 kg. Ini adalah sangat ringan dan mudah untuk hilang kawalan. Untuk mengatasi masalah ini, ia adalah mustahak untuk mengira di mana perlunya sayap itu diletakkan di atas rangka pesawat dan jenis airfoil apakah yang sesuai digunakan untuk sayap berkenaan. Jikalau pilihan dibuat dengan cuai, UAV ini berkemungkinan tidak boleh terbang atau ianya dapat terbang tetapi dengan keadaan yang buruk. Analisa terhadap parameter sayap telah dijalankan dengan perisian komputer tertentu yang berkebolehan untuk bertindak sebagai terowong udara maya. Pemilihan sayap yang terbaik seterusnya akan dimodelkan dengan menggunakan perisian CAD sebagai keputusan akhir projek ini.

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Over past the decade, the aircraft technology already evolves into various types of shape and design which is base on the usage of the aircraft itself. There are two types of aircraft that widely be used which are the manned aircraft or aviation and unmanned aerial vehicles (UAV). The UAV is an aircraft without a pilot where it fly on its own if there is flight plans been programmed, but if not it will be controlled from a remote controller.

UAV can be divided into six categories of role which are Target and Decoy, Reconnaissance, Combat, Logistics, Research and Development, and Civil and Commercial UAV. Most of the categories are belong to the military field where there is certain part of military mission that cannot be completed by men. There are widely usages of the UAV in the military works but less in civil area. In the market place, the UAV can be divided by various sizes such as the small scale the hand-held Micro Air Vehicle (MAV), (Hwang, H.C. et al., 2004), the Mini UAV such as Dragon Eye, (Cambone, S.A. et al., 2005) and also the large-scaled UAV such as Predator, (Park, K. et al., 2008).

The widely usage of the UAV has increase the number of the UAV design itself where we can see different type of wing, control systems and shape will be used in the UAV itself. The most important part of the UAV is the wing or airfoil where the wing itself will control the stability and will determine whether the UAV will fly or not.

If the aerodynamic efficiency and optimization of aircraft structures can be improves, the cost of the construction can be reduced and minimize (Goraj, Z. 2005). This feature has stated that the important role of the wing itself to the UAV. Thus, this study will cover up the wing or airfoil area of the UAV only which discuss the best airfoil to be use in certain parameter, such as angle of attack, wing aspect ratio, wing type and others.

Specifically, this research will cover all the process needed in the aircraft engineering subject from the conceptual design, preliminary design and detail design until the result shown the best wing configuration to be used for the new UAV.

1.2 PROJECT OBJECTIVE

The main objective of this project is to design a suitable wing configuration for the new type reconnaissance UAV.

1.3 PROJECT SCOPES

This project will cover all the project scopes below:

a. Airfoil selection (NACA, Clark Y, Aquila, etc)
b. Airfoil properties (C_L, AC, C_M, etc)
c. Type of wing (Delta, Straight, etc)
d. Wing configuration (position, center of gravity, etc)
e. Wing placement

1.4 PROBLEM STATEMENTS

In this project, the major problems that need to be handled are to design a new UAV that will have the configuration based on the project assumptions and also the technical task. In developing new type of UAV, many criteria need to be taken into considerations. The criteria that must be taking care are the external design, conceptual design, preliminary design, detail design, flight testing and manufacturing. All of these criteria cannot be completed if each part of the UAV have not been analyze completely.

For UAV, beside the control system, the most important part of the UAV is to have perfect wing configuration, where it needs to be fit with the external design of the UAV project as to make sure it can provide the UAV to fly very smoothly. Therefore, in this project, all of these problems will be taken very positively into considerations and will be analyze later on, so that the target to build a UAV that will fly will be achieve.

1.5 PROJECT ASSUMPTIONS

In this project, few resolutions will be used in the conceptual design as to generate the Matching Diagram in next chapter:

Cruise Speed, V_{cr}	: 60 km/h
Loiter Speed, V_{ltr}	: 45 km/h
Endurance, E	: 1 hour
Range, R	: 10 km (for 30 minutes surveillance work)
Altitude, h	: 1000ft
Take off distance, s_{TO}	: 10m (launch by hand)
Landing distance, s_L	: 100m

REFERENCES

This thesis is prepared based on the following references

Alias, A.B.S., Kamaruddin, A.M.N.A., Epps, A.V., Mustafar, M. and Amin, N.A.M. 2008. *Morphing Wing HALE UAV, Aircraft Design*. University of Adelaide, Australia.

Anderson, J.D. 1999. *Aircraft Performance and Design*. Singapore: Mc Graw Hill.

Avalakki, N., Bannister, J., Chartier, B., Downie, T., Gibson, B., Gottwald, C., Moncrieff, P. and Williams, M. 2007. Design, Development and Manufacture of a Search and Rescue Unmanned Aerial Vehicle. University of Adelaide, Australia.

Balvanes, K., Cook, B., Horstmann, A., Middleton, R. and Rogers, C., 2008. Coastal Watch UAV, University of Adelaide.

Cambone, S.A., Krieg, K.J., Pace, P. and Linton, W. 2005. *Unmanned Aircraft Systems Roadmap 2005-2030*. USA: Office of the Secretary of Defense.

Cengel, Y.A., Cimbala, J.M. 2006. *Fluid Mechanics, Fundamental and Applications*. Singapore: Mc Graw Hill.

FlyCamOne2 Technical Data (online). http://s3.amazonaws.com/hobbylobbypdf/aa1130v2.pdf (7 February 2009).

GlobalSecurity.org. 2008. Unmanned Aerial Vehicle (UAVs) – Military Aircraft (online). http://www.globalsecurity.org/intell/systems/uav-intro.html (4 February 2009).

Goraj, Z. 2005. Design challenges associated with development of a new generation UAV. *Aircraft Engineering and Aerospace Technology: An International Journal*, **77** (5): 361-368.

Hwang, H.C. and Yoon, K.J. 2004. 2004 International MAV Competition and Analysis for the MAV Technologies. *Journal of KSAS (Korean).*

Jones, K.D., 2009. Deciphering the NACA 4/5-digit Airfoil Numbering System (online). http://aa.nps.edu/~jones/online_tools/panel2/naca/ (16 February 2009).

Jones, K.D., 2009. The NACA 4-digit airfoil series (online).http://aa.nps.edu/ ~jones/online_tools/panel2/naca/ (16 February 2009).

Lake, D. 2007. Unmanned Aerial Vehicle: Handbook 2007, Spehard.

Park, K., Han, J.W., Lim, H.J., Kim, B.S. and Lee, J. 2008. Optimal Design of Airfoil with High Aspect Ratio in Unmanned Aerial Vehicles. *World Academy of Science, Engineering and Technology 40 2008.*

Model Motors s.r.o. 2006. Motor catalogue (online). http://www.modelmotors. cz/index.php?page= 61& product=2217&serie=9DPG&line=GOLD (7February 2009).

NASA Quest. Size (area) and shape of the wing (online). http://quest.nasa.gov/aero/ planetary/atmospheric/aerodynamiclift.html (16 February 2009).

Roskam, J. 2005. *Airplane Design, Part I: Preliminary Sizing of Airplanes*, DAR Corporation. 4th ed. USA: DAR Corporation.

Roskam, J. 2004. *Airplane Design, Part II: Preliminary Configuration Design and Integration of the Propulsion System*. 4th ed. USA: DAR Corporation.