UNIVERSITI PUTRA MALAYSIA

NUMERICAL ANALYSIS OF TUBERCLES LEADING EDGE FOR UNMANNED AERIAL VEHICLE COMPOSITE WING

ERNNIE ILLYANI BINTI BASRI

FK 2020 56

NUMERICAL ANALYSIS OF TUBERCLES LEADING EDGE FOR UNMANNED AERIAL VEHICLE COMPOSITE WING

By

ERNNIE ILLYANI BINTI BASRI

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

January 2020

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

NUMERICAL ANALYSIS OF TUBERCLES LEADING EDGE FOR UNMANNED AERIAL VEHICLE COMPOSITE WING

By

ERNNIE ILLYANI BINTI BASRI

January 2020

Chair: Kamarul Arifin bin Ahmad, PhD
Faculty: Engineering

The demand of Unmanned Aerial Vehicle (UAV) technology received growing interest from today's engineers in designing and manufacturing the products within a short time and at reasonable price. The wide availability of modern and developing composite materials and the aid of computer systems had made the demand becoming possible and achievable. The proposed research consist of fundamental numerical work and experimental work. The study applied the Finite Element (FE) analysis and developed a standardized numerical approach for structural optimization subjected to tubercles design at the leading edge of NACA4415 wing with composite material, known as FE-ACP simulation. The study is crucial in order to optimize the structural behavior of spherical tubercles pattern at the leading edge of straight, untapered and unswept wing. The previous studies proved its superior aerodynamic advantages from computational fluid dynamics (CFD) perspective on the same tubercles design. Therefore, structural characteristic including the external and internal components of the wing should be taken into consideration to achieve the superiority of high strength-to-weight ratio in regards to the application of UAV. Up-to-date, the simulation software, ANSYS is widely used in solving the FE problems subjected to composite materials. The composite modelling of the wing design is developed using ANSYS Composite PrePost (ACP) module, whereby a preliminary simulation is prepared in terms of the designation of composite materials and its impact of wing deformation. In details, the parametric study is carried out, by which the structure of the wing is optimized through optimal composite ply orientation and optimal design configuration subjected to wing stiffness and also criticality of loading requirements for structural failure. Failure criteria of Tsai-Wu and Hashin play important role in determining the optimal design of tubercles wing subjected to strength and stiffness, which is able to be obtained. The experimental study of the designation of composite at the wing skin is conducted in order to prove the simulation validity through material

characteristics. Hence, from this study, 50.27% improvement is obtained by applying the TLE wing design with semi-monocoque-foam-reinforced proven the significant of current research area on optimal performance of wing in the perspectives of composite structural optimization.

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

ANALISIS BERANGKA PADA PINGGIR DEPAN TUBERKEL SAYAP KOMPOSIT PESAWAT UDARA TANPA PEMANDU

Oleh

ERNNIE ILLYANI BINTI BASRI

Januari 2020

Pengerusi: Kamarul Arifin Ahmad, PhD
Fakulti: Kejuruteraan

Permintaan untuk teknologi pesawat udara tanpa pemandu (UAV) mendapat perhatian yang semakin meningkat dari jurutera hari ini bagi merekabentuk dan pembuatan produk dalam masa yang singkat dan pada harga yang berpatutan. Ketersediaan luas bahan komposit dan bantuan sistem berkomputer yang moden dan berkembang maju telah membawa kepada permintaan ini menjadi mungkin dan boleh dicapai. Penyelidikan yang dicadangkan merangkumi kerja-kerja asas berangka dan eksperimen. Kajian ini menggunakan analisis unsur terhingga (FE) dan pendekatan berangka berpiawai yang telah dibangunkan untuk pengoptimuman struktur tertakluk kepada rekabentuk tuberkel pada pinggir depan sayap NACA4415 dengan bahan komposit, yang dikenali sebagai simulasi FE-ACP. Kajian ini sangat penting untuk mengoptimumkan tingkah laku struktur ke atas corak tuberkel berbentuk sfera terletak pada pinggir depan sayap yang lurus, tidak tirus dan tidak tersapu. Kajian terdahulu telah membuktikan ianya menunjukkan kelebihan aerodinamik yang unggul dari perspektif pengkomputeran dinamik bendalir (CFD) pada rekabentuk tuberkel yang sama. Oleh itu, ciri-ciri struktur merangkumi komponen-komponen sayap luaran dan dalaman yang perlu dipertimbangkan bagi mencapai keunggulan nisbah tinggi kekuatan-kepada-berat dalam aplikasi UAV. Sehingga kini, perisian simulasi, ANSYS telah luas digunakan dalam menyelesaikan masalah berkaitan FE yang dikaitkan dengan bahan-bahan komposit. Pemodelan komposit pada rekabentuk sayap telah dibangunkan dengan menggunakan modul ANSYS Komposit Sebelum/Selepas (ACP), di mana simulasi awal disediakan dari segi penentuan bahan komposit serta kesan terhadap ubah bentuk sayapnya. Secara terperinci, kajian parametrik telah dijalankan, yang mana struktur sayap dioptimumkan melalui orientasi piawai komposit yang optimum dan konfigurasi rekabentuk yang optimum tertakluk kepada kekakuan sayap dan juga keperluan bebanan yang kritikal untuk menentukan kegagalan

struktur tersebut. Kriteria kegagalan iaitu Tsai-Wu dan Hashin memainkan peranan penting dalam menentukan rekabentuk sayap tuberkel yang optimum tertakluk kepada nisbah tinggi kekuatan dan kekakuan, yang mana ianya telah dapat diperolehi. Kajian ekperimen tentang penetapan komposit pada luaran sayap telah dijalankan juga bagi membuktikan kesahihan simulasi melalui ciri-ciri bahan. Oleh yang demikian, sebanyak 50.27% pembaikan diperolehi dengan menggunakan sayap TLE bersama rangka tunggal-berbusa yang diperkuatkan membuktikan kepentingan bidang penyelidikan yang terkini ke atas prestasi sayap optimum dalam perspektif pengoptimumam struktur komposit.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my greatest gratitude to my supervisor, Associate Professor Ir. Dr. Kamarul Arifin bin Ahmad for his guidance, which enable me to complete this research work successfully. Also, to my co-supervisors, Professor Ir. Ts. Dr. Mohamed Thariq bin Hameed Sultan and Professor Faizal bin Mustapha for their thoughtful supervision and valuable suggestion throughout my study.

I would like to thank Universiti Putra Malaysia for providing me the best facilities and conducive environment throughout my postgraduate study period. Special thanks to my colleagues, Mr. Firdaus bin Abas, Mr. Farid bin Bajuri, Dr. Ain Umaira binti Md Shah, Dr. Syafiqah Nur Azrie binti Safri, for their continuous support with fruitful ideas and comments. Thousand thanks to Dr. Adi Azriff Basri for his guidance in teaching and exposing me towards mastering the software of ANSYS, specifically in the analysis of composite and ANSYS Workbench. Not to forget, thousand thanks to Laboratory of Composite, UPM for giving me the opportunity to use their facilities for experiment.

My sincere gratitude and deepest appreciation to my parents, Maria Zulyani binti Mohd Zain and Basri bin Roslan whose continuously support and encourage for my long life journey of learning. Not to forget my family members, Nur Khairiyah binti Basri, Khairul Ikhwan binti Basri, Anis Syahirah binti Basri for their continuous encouragement.

My utmost gratitude and thanks to my husband, Adi Azriff bin Basri, for his constant source of motivation and splendid support during the challenges of graduate school and life. He is the one who stood by me through thick and thin with patience and tolerance during my entire study. And, also the one that ensure to finish my PhD completely and successfully.

I am also indebted to every individual for their involvement directly and indirectly throughout this research. I really appreciate their relevant comments and encouragement during my research period. Thank you for always being there and making this pursuit a valuable journey.

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 Philosophy. The members of the Supervisory Committee were as follows:

Kamarul Arifin bin Ahmad, PhD
Associate Professor Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohamed Thariq bin Hameed Sultan, PhD
Professor Ir. Ts
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Faizal bin Mustapha, PhD
Professor Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Member)

____
ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ________________________ Date: __________________

Name and Matric No.: _Ernnie Illyani Binti BASRI (GS44875) _____

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature:	
Name of Chairman of Supervisory Committee:	Associate Professor Ir. Dr. Kamarul Arifin bin Ahmad
Signature:	
Name of Member of Supervisory Committee:	Professor Ir. Ts. Dr. Mohamed Thariq bin Hameed Sultan
Signature:	
Name of Member of Supervisory Committee:	Professor Ir. Faizal bin Mustapha

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACP	ANSYS Composite PrePost
AoA	Angle of Attack
CAD	Computer Aided Design
CFD	Computational Fluid Dynamic
CLT	Classical Laminate Theory
FE-ACP	Finite Element-ANSYS Composite PrePost
FEA	Finite Element Analysis
FEM	Finite Element Method
IRF	Inverse Reserve Factor
MAV	Micro-Aerial Vehicle
MoS	Margin of Safety
RF	Reserve Factor
SR	Strength Ratio
TLE	Tubercles Leading Edge
UAV	Unmanned Aerial Vehicle

LIST OF SYMBOLS

3D	Three-dimensional
A	Amplitude
λ	Wavelength
h	Thickness of laminate
u	Displacement at x-direction
v	Displacement at y-direction
σ	Stress
ε	In-plane strain
$\dot{\gamma}$	Out of-plane strain
κ	Curvature of mid-plane
$[C]$	Element stiffness matrix
F	Nodal force
δ	Displacement of nodal points of particular element
$[B]$	Matrix of strain-displacement
$[N]$	Matrix of shape vector
$[\boldsymbol{E}]$	Matrix of stiffness of particular material
$[\tilde{S}]$	Shear stiffness matrix for shell element
V_f	Fibre volume fraction
ρ_f	Density of fibres
ρ_m	Density of cured resin/hardener matrix
m_f	Fibre mass
W_f	Weight fraction

CHAPTER 1

INTRODUCTION

1.1 Overview

This chapter describes the general idea of the current work. First, the theoretical foundations of this research are presented in research background and further elaborated in second section discussing on tubercles design at the leading edge of the wing. Then, in the problem statement section, the current situation in tubercles wing design configuration is discussed. The research objective is stated in the fourth section. The scope of the thesis is described in the final section.

1.2 Research background

An unmanned aerial vehicle (UAV) is a pilotless aircraft that can be remotely controlled from a ground control room. The interest in UAV development is growing in recent years due to its capabilities of utilizing relatively more reasonably priced airplanes without the on-board human operator especially when the missions involves long operational time and severe risks (Bento, 2008; Turgut, 2007). The extensive use of UAVs continued throughout the time with the development of improved UAVs capability which different kinds of UAV platforms have different mission and applications. The example of UAV for surveillance and reconnaissance applications in Malaysia is Alliance Unmanned Developmental Research Aircraft (ALUDRA MK 1), as depicted in Figure 1.1.

Figure 1.1: Aludra MK1 for surveillance and reconnaissance mission in Sabah, Malaysia
(Source: (Koo et al., 2012)

Prior to the development of UAV, the basic inspiration and motivation for flying has come from the capabilities of birds, insects and aquatic animals that able to generate efficient lift and thrust with same wing planform. This bio-inspirations attempts to produce engineered systems that possess characteristic in aeronautical applications. In fact, this attempts has inspired human towards replicated or mimicked the features and capabilities of the biological evolution in human engineered systems. Hence, this inspiration lead to the design of new technologies and the improvement of conventional ones.

The notion of characterize animal features is far from new. Leonardo da Vinci, the first developed early blueprints for 'flying machine' inspired by a bird in adopting flapping mechanism to produce lift and thrust ((Bar-Cohen, 2006). Then, the Wright Brothers succeeded in creating and flying the first airplane off the ground by adapting the ability of pigeon's wing to create lift. Throughout the biological evolution, the increasing demand integrating the structure and functions replicated the features of animal species has driven the designers towards more simple and efficient design. Moreover, one can take biologically identified anatomical structures and their functions in engineering applications, as in Table 1.1.

Table 1.1: Biomimetics studies in engineering applications

Category	Animal	Anatomical structures	Anatomical Advantages	Engineering application	References
Flying	Birds	Limbs and feathers	The forces of lift, thrust, drag and gravity influence the flight patterns of birds	Flapping UAVs	(Bachmann & Wagner, 2011)
	Owls	Feathers	Fly silently and helps to absorb aerodynamic sound, suppress vibrations when waves of sound come crushing over the wing	UAVs Wind turbines	(Bachmann & Wagner, 2011)
	Wild geese	Wings	Ascending air current with less effort	AIRBUS	(Alerstam et al., 1990)
	Insects (dragonfly)	Multiple wings and legs	Pressure gradients for lift and thrust by flapping	small UAVs (micro aerial vehicle)	(Naqvi et al., 2015)
	Bats	Limbs	Membrane of skin that stretches between arms and leg help to produce lift	small UAVs (micro aerial vehicle)	(Naqvi et al., 2015; Norberg, 2012)
Aquatic	Whale	Flipper (Tubercles effect)	Tubercles on the leading edge produces greater lift and less drag than a smooth surface fin	small UAVs (micro aerial vehicle)	(Bushnell & Moore, 1991; Fish & Battle, 1995; Fish & Lauder, 2006; Miklosovic et al., 2007; Miklosovic et al., 2004)

Referring to Table 1.1, the basic motivation for flying has always come from millions of species of birds and insects. They efficiently generate lift and thrust using the same wing planform. Specialized feathers of the owl have the ability to fly silently with its unique wing features of trailing edge fringe and velvety down that helps to absorb aerodynamic sound (Bachmann & Wagner, 2011). Whereas, the morphology of insects is way more complex which aerodynamically produced pressure gradients for lift and thrust by flapping from multiple wings and legs. In fact, dragonfly inspired the ideas to build four-winged MAVs (Naqvi et al., 2015). Despite that, the limbs of bats also influenced flight performance such as the geometry of wings and bones, compliant skin and bones, distribution of sensory hairs across wings and physiology of musculature that drives the wings (Naqvi et al., 2015; Norberg, 2012). In the late 1990s, Frank E. Fish discovered the tubercles effect of the flipper of humpback whale, act like a wing which contributed to the superior aerodynamic maneuverability that allowing greater lift and less drag than a smooth surface fin (Fish & Battle, 1995). The humpback whale flipper received tremendous attention on the influence of rounded tubercles located on the leading edge of flippers in order to design effective wings involving aerodynamic performance (Bushnell & Moore, 1991; Fish & Battle, 1995; Fish & Lauder, 2006; Miklosovic et al., 2007; Miklosovic et al., 2004).

1.3 Emerging of bio-inspired application: Tubercles Leading Edge (TLE)

One of the baleen whale species, known as Megapteranovaeangliae that has massive size of 40 tons and 15 metres in length, as in Figure 1.2. The highly articulated pectoral fins with characteristic tubercles on the leading edge provide great maneuverability for hunting krill, plankton and small shoals of fish (Fish et al., 2011)

Figure 1.2: Tubercles on the leading edge of a humpback whale
(Source: Fish et al., 2011)

The humpback whale has a unique maneuvering ability to undertake sharp movements to catch prey. The sharp and high speed banking turns of the humpback whale are favoured by the high lift or drag characteristic of the combination of the tubercles and the high aspect ratio of the flippers. The tubercles provide the benefit in maneuverability and in capturing the prey by acting as leading edge control devices to maintain lift and avoid stall at high angles of attack (Easter et al., 2013; Serres et al., 2011; Swartz et al., 2007). The presence of tubercles of the humpback whale flipper inspired the design of airplane wing and underwater vehicle. The simultaneous achievement of increased lift and reduced drag results in an increase aerodynamic efficiency. Hansen (2012) proposed the tubercle geometric parameters are amplitude, A and wavelength, λ, by which the optimal ratio for determining the shape of foil at the leading edge, as depicted in Figure 1.3.

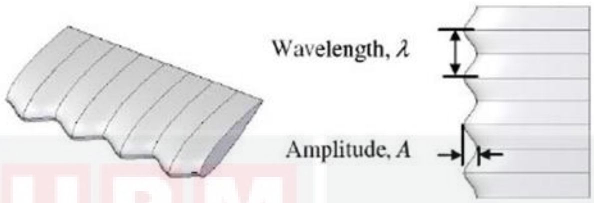

Figure 1.3: Amplitude and wavelength of sinusoidal tubercles
(Source: Hansen, 2012)

Much progress has been made in the computational fluid dynamics (CFD) analysis to assess different external shapes based on parametric designs. In particular, aerodynamic perspective potentially gain endurance by reducing drag. However, the structural perspective also should be considered as it contributed towards weight reduction of the wing which can be translated into a lighter UAV with an increased endurance and a reduced speed stall (Landolfo, 2008). Noteworthy, Weisler et al., (2017) also highlighted the competing requirement of capability for performing in aerial (air) and underwater domains, whereby the efficient air flight requires a lower density airframe which decreases wing loading and stall speed while increasing efficiency. This may lead to serious attention for ideal aero-structural design due to the complexity of wing designs by considering other structural perspectives prior to manufacturing and testing UAVs under the real-world condition.

1.4 Problem statement

One of the critical element of aircraft is the wing design. Kumar et al., (2015) highlighted that fuselage and wing are the two essential element of aircraft, by which 80% of lift load is acted on the wings while the remaining 20% is acted on the fuselage. In today's aeronautical researches, the advancement of multidisciplinary optimisation performances and their applications towards the ideal aero-structural design is one of the main factor contributing to continuous development in UAV designs. For the TLE wing design, the complex surface element of the wavy pattern or spherical shape at the leading edge of the wing is notably increase the aerodynamic performance particularly along the center between crest and through the tubercles on the lower surface of the wing (Hansen & Horst, 2008). Though much progress of TLE wing has been made in the capability of computational fluid dynamics to analyse difference external shapes of TLE design, the structural aspects of the design optimisation complication have not enjoyed the same attention.

There are several issues related to TLE structural design, namely:

i. Lack of works in the structural mechanics and other possible uncertainties in materials characterization and manufacturing practices. As TLE is the current wing design, many researchers focused on the aerodynamic aspects. Hence, there is a knowledge gap in the structural analysis
ii. Knowledge gap in understanding the role of structure wing components such as spars and ribs or other alternative reinforcement of the wing (Aftab & Ahmad, 2017; Kanesan et al., 2014)
iii. Lack of extensive use of computational structural analysis tools for high fidelity design analysis
iv. Limitation information on the design flexibility and structural dimensional stability with requirement of the high strength-to-weight ratio to meet the demand of modern UAV

Therefore, the current work employs ANSYS Composite Prepost (ACP) module, known as FE-ACP provide superior performance of aero-structural design of TLE wing under various conditions. In addition, the limitations of complexities in the design of TLE wing can be technically solve with the aid of fidelity analysis. Hence, the current FE-ACP can provides the structural response in technical perspectives such as loading and related structural-material stiffness in order to observe the optimal aero-structural performance of the developed TLE of UAV wing.

The simulation based on the structural and manufacturing aspects such as realistic airfoil for UAV models, geometrical shape, ease of manufacture, surface finish quality and price for preparing the materials of TLE wing may provide better understanding on the structural and composite response of complex design of TLE wing. The novelty of the current research work is the application of FE-ACP technique on the wing with tubercles design at the leading edge in terms of composite materials lamination and structure deformation. The mentioned issues related to TLE structural design mainly the increase studies on CFD from aerodynamic perspectives highlighted the least attention on the structural mechanics including computational structural analysis and the needs of design flexibility and structural components. Therefore, the analysis on the composite materials and loading mechanisms are the essential elements that contributed to critical findings in terms of structural efficiency on mechanical perspectives

1.5 Research objectives

The main objective of this research is to investigate the structural response of TLE wing of NACA4415 airfoil subjected to composite materials using the application of Finite Element-ANSYS Composite Prepost (FE-ACP). In specific, this research are:

1. To determine a standard method for conventional wing by conducting two validations of numerical structural analysis and experimental tests.
2. To carry out the real work of 3D numerical analysis of FE-ACP to investigate the structural performance of TLE wing design
3. To investigate the optimal composite ply orientation and optimal design configuration subjected to wing stiffness and also criticality of loading requirements for structural failure

1.6 Scope of work

This research focus on the structural investigation of the static wing structure of NACA4415 airfoil with additional design of tubercles at the leading edge of the wing, known as tubercles leading edge (TLE). In order to prepare the standard technique of presenting the investigation of the wing structure of TLE, the basic understanding needed to be developed from the design of conventional wing with clean leading edge. Hence, the real work on TLE wing with composite materials is performed with regards to the presence of rib-reinforcement of spars and ribs that support the whole wing structure. Several parameters are taken into consideration such as total deformation, stress and strains. The total deformation defined the structural characteristic of the wing models, whereby all the stresses and strains data characterized the material behaviour under applied loading conditions. Besides that, experiment testing on the laminated composite materials of conventional wing skin is also investigated to understand the material behaviour under tensile and flexural loading. This research is mainly to understand the structural behaviour according to additional tubercles patterns at the leading edge as well as to investigate the composite materials impacts towards the whole structure of the wing. To the best of our knowledge, less work on the structural analysis has driven this research towards optimal structural performance of the TLE wing.

1.7 Thesis outline

The thesis contains seven chapters.

- Chapter 1 provides the overview of Unmanned Aerial Vehicle (UAV), bio-inspired applications of Tubercles Leading Edge (TLE), and objectives of the research.
- Chapter 2 provides the previous works describing evolution of conventional UAV wing with normal airfoil and limitation of TLE wing. The chapter also provides the approaches in numerical simulation and experiment.
- Chapter 3 discusses on the methodology adopted in this research. The conceptual technique of finite element modeling are explained in detail. Despite that, this chapter also explains the experimental setup for flexural and tensile tests.
- Chapter 4 reveals the validation of NACA4415 composite UAV wing using FE-ACP simulation with existing research paper. The validation of

computational FE-ACP with the experimental studies are also included in this chapter.

- Chapter 5 describes the details on structural design and performance of UAV composite wing with TLE using FE-ACP.
- Chapter 6 presents the parametric studies on structural performance in terms of optimal ply orientation, monocoque-foam-reinforcement and loading requirements for failure.
- Chapter 7 gives the conclusion and recommendations for future works.

REFERENCES

Aftab, S. M. A., & Ahmad, K. A. (2014). NACA 4415 Wing Modification Using Tubercles - A Numerical Analysis. *Applied Mechanics and Materials*, *629*, 30–35.

Aftab, S. M. A., & Ahmad, K. A. (2017). CFD Study on NACA 4415 Airfoil Implementing Spherical and Sinusoidal Tubercle Leading Edge. *PLoS ONE*, *12*(8), 1–27.

Alerstam, T., Gudmundsson, G. A., Jonsson, P. E., Karlsson, J., & Lindstrom, A. (1990). Orientation, migration routes and flight behaviour of knots, turnstones and brant geese departing from Iceland in spring. *Arctic*, *43*(3), 201–214.

Alshaya, A., Shual, X., & Rowlands, R. (2016). Thermoelastic Stress Analysis of a Finite Orthotropic Composite Containing an Elliptical Hole. *Experimental Mechanics*, *56*(8), 1373–1384.

Altenbach, H., Altenbach, J. W., & Kissing, W. (2004). *Mechanics of Composite Structural Elements* (Vol. 49). Springer US.

Anderson, J. D. (2011). *Chapter 7: Wing Loading*. *Fundamentals of Aerodynamics* (5th Editio). McGraw-Hill Higher Education.

ANSYS, R. 15. . (2013). Composite Model Techniques. In *ANSYS Composite PrepPost User ' s Guide* (pp. 59–100). Canonsburg, PA.

ASTM D 3039. (2014). Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials. *Annual Book of ASTM Standards*, *15*, 1–13.

ASTM D790-03. (2003). Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials. *Annual Book of ASTM Standards*, *14*(2), 1–11.

Autio, M., Parviainen, H., & Pramila, A. (1992). Accuracy of the finite element method in analyzing laminated plate and pipe structures. *Mechanics of Composite Materials*, *28*(3), 236–245.

Bachmann, T., & Wagner, H. (2011). The three-dimensional shape of serrations at barn owl wings: Towards a typical natural serration as a role model for biomimetic applications. *Journal of Anatomy*, *219*(2), 192–202.

Bajuri, F., Mazlan, N., & Ishak, M. R. (2017). Effect of silica nanoparticles in kenaf reinforced epoxy: Flexural and compressive properties. *Pertanika Journal of Science and Technology*, *25*(3), 1029–1038.

Bar-cohen, Y. (2005). *Biomimetics : biologically inspired technology*. *CRC Press*.

Bar-Cohen, Y. (2006). Biomimetics--using nature to inspire human innovation. *Bioinspiration & Biomimetics*, *1*(1), P1–P12.

Barbarino, S., Bilgen, O., Ajaj, R. M., Friswell, M. I., & Inman, D. J. (2011). A Review of Morphing Aircraft. *Journal of Intelligent Material Systems and Structures*, *22*(9), 823–877.

Barry, T. D. (2011). *Design and Analysis of the Proposed Composite Post and Related Structural Elements - Study of a Post Structure in Composite Material for Rail Line Electrification Assembly*. University of Seville.

Basri, E. I., Basri, A. A., Abas, M. F., Mustapha, F., Sultan, M. T. H., & Ahmad, K. A. (2019). UAV NACA4415 wing structural performance analysis subjected to external aerodynamic load using Schrenk's approximation. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, *60*(2), 178–190.

Bento, M. D. F. (2008). Unmanned Aerial Vehicles : An Overview. *InsideGNSS*,

54–61.
Bolzon, M. D., Kelso, R. M., & Arjomandi, M. (2015). Tubercles and Their Applications. *Journal of Aerospace Engineering*, *29*(1), 040150131–0401501310.
Bushnell, D. M., & Moore, K. J. (1991). Drag reduction in nature. *Annual Review of Fluid Mechanics*, *23*, 65–79.
Chauhan, H. R., Panwar, H., & Rastogi, V. (2017). Structural Design & Optimization Of An Unmanned Aerial Vehicle Wing For SAE Aero Design Challenge. *International Journal of Advance Research and Innovation*, *5*(1), 24–29.
Chen, J., Yang, N., Li, F., & Chen, Z. (2001). Effects of stacking sequence on the damage growth in quasi-isotropic CFRP laminates. *Materials Science Research International*, *7*(3), 178–185.
Chitte, P., Jadhav, P. K., & Bansode, S. . (2013). Statistic and Dynamic Analysis of Typical Wing Structure of Aircraft using Nastran . *International Journal of Application or Innovation in Engineering and Management*, *2*(7), 321–326.
Church, clinton S. (2003). Composite Structures for High-altitude UAVs. In *Proceedings of the 2nd AIAA "Unmanned Unlimited" Systems, Technologies and Operations, September 15-18, 2003, San Diego, California* (pp. 6508–6515). San Diego, California: AIAA.
Corsini, A., Delibra, G., & Sheard, A. G. (2013). On the role of leading-edge bumps in the control of stall onset in axial fan blades. *Journal of Fluids Engineering-Transactions of the Asme*, *135*(8), 0811041–0811048.
Custodio, D. (2007). *The effect of humpback whale-like leading edge protuberances on hydrofoil performance*. Worcester Polytechnic Institute.
Daniel, I. M., & Ishai, O. (2006). *Engineering Mechnics of Composite Materials*. *Oxford University Press* (2nd Editio). New York: Oxford Univeristy Press, Inc.
Devi, G. R., & Palanikumar, K. (2018). Analysis on drilling of woven glass fibre reinforced aluminium sandwich laminates. *Journal of Material Research and Technology*, *In press*, 1–20.
Dong, C., Ranaweera-Jayawardena, H. A., & Davies, I. J. (2012). Flexural properties of hybrid composites reinforced by S-2 glass and T700S carbon fibres. *Composites Part B: Engineering*, *43*(2), 573–581.
Dunphy, B. ., & George, W. . (1983). Aerospace Manufacture and Maintenance. In *Encyclopedia of Occupational Health and Safety* (3rd ed., pp. 1–15). Geneva, ILO.
Easter, S., Turman, J., Sheffler, D., Balazs, M., & Rotner, J. (2013). Using advanced manufacturing to produce unmanned aerial vehicles: a feasibility study. *SPIE Defense, Security, and Sensing. International Society for Optics and Photonics*, *8742*, 8742041–87420416.
Espada, D. R. (2011). *Aerodynamic assessment of humpback whale ventral fin shapes*.
Fernandes, I., Sapkota, Y., Mammen, T., Rasheed, A., Rrbrllo, C. L., & Kim, Y. H. (2013). Theoretical and Experimental Investigation of the Leading Edge Tubercles on the Wing Performance. In *2013 Aviation Technology, Integration, and Operations Conference August 12-14, 2013, Los Angeles, CA* (pp. 4300–4340).
Finnigan, P. M., Kela, A., & Davis, J. E. (1989). Geometry as a basis for finite element automation. *Engineering with Computers: An International Journal*

of Simulation-Based Engineering, *5*(3), 147–160.
Fish, F. E., & Battle, J. M. (1995). Hydrodynamic-Design of the Humpback Whale Flipper. *Journal of Morphology*, *225*(1), 51–60.
Fish, F. E., Howle, L. E., & Murray, M. M. (2008). Hydrodynamic flow control in marine mammals. *Integrative and Comparative Biology*, *48*(6), 788–800.
Fish, F. E., & Lauder, G. V. (2006). Passive and Active Flow Control By Swimming Fishes and Mammals. *Annual Review of Fluid Mechanics*, *38*(1), 193–224.
Fish, F. E., Weber, P. W., Murray, M. M., & Howle, L. E. (2011). The tubercles on humpback whales' flippers: Application of bio-inspired technology. *Integrative and Comparative Biology Advance Access*, *51*(1), 1–11.
Gamboa, P., Alexio, P., Vale, J., Lau, F., & Suleman, A. (2007). Design and Testing of a Morphing Wing for an Experimental UAV. In *The Applied Vehicle Technology Panel Symposium (AVT-146)* (pp. 1701–1730).
Gamboa, P., Vale, J., Lau, F. J. ., & Suleman, A. (2009). Optimization of a Morphing Wing Based on Coupled Aerodynamic and Structural Constraints. *AIAA Journal*, *47*(9), 2087–2104.
Gaunt, J. D., Flores, J. C., & Perry, V. A. (2010). *Design, Fabrication, Structural Testing, and Numerical Analysis of a Small Scale Composite Wing*. California Polytechnic State University, San Luis Obispo In.
Gawad, A. F. A. (2013). Utilization of Whale-Inspired Tubercles as a Control Technique to Improve Airfoil Performance. *Transaction on Control and Mechanical Systems*, *2*(5), 212–218.
Grant, R. J., Lorenzo, M., & Smart, J. (2007). The effect of Poisson's ratio on stress concentrations. *Journal of Strain Analysis for Engineering Design*, *42*(2), 95–104.
Grodzki, W., & Łukaszewicz, A. (2015). Design and manufacture of umanned aerial vehicles (UAV) wing structure using composite materials. *Materialwissenschaft Und Werkstofftechnik*, *46*(3), 269–278.
Haftka, R. T., & Gurdal, Z. (1992). Elements of Structural Optimization. In *Solid Mechanics and Its Applications* (3rd Editio). Dordrecht Kluwer Academic Publisher.
Hansen, K. L. (2012). *Effect of leading edge tubercles on airfoil performance*. *PhD Dissertations*.
Hansen, K. L., Kelso, R. M., & Dally, B. B. (2011). Performance Variations of Leading-Edge Tubercles for Distinct Airfoil Profiles. *AIAA Journal*, *49*(1), 185–194.
Hansen, L. U., & Horst, P. (2008). Multilevel optimization in aircraft structural design evaluation. *Computers and Structures*, *86*(1–2), 104–118.
Harrison, J. P. (2011). Wind turbine noise. *Bulletin of Science, Technology and Society*, *31*(4), 256–261.
Hashin, Z. (1980). Failure Criteria for Unidirectional Fibre Composites. *Journal of Applied Mechanics*, *47*(2), 329–334.
Heintz, C. (2002). Wood , Aluminum , Steel and Composites. In *Aircraft Design and Construction* (pp. 1–11). Missouri, USA: Zenith Aircraft.
Hinton, E., Rao, N. V. R., & Sienz, J. (1992). Finite element structural shape and thickness optimization of axisymmetric shells. *Engineering Computations*, *9*(5), 499–527.
Horn, T. J., & Harrysson, O. L. A. (2012). Overview of current additive manufacturing technologies and selected applications. *Sci Prog*, *95*(3), 255–282.

Huang, R., Riddle, M., Graziano, D., Warren, J., Das, S., Nimbalkar, S., … Masanet, E. (2015). Energy and emissions saving potential of additive manufacturing: The case of lightweight aircraft components. *Journal of Cleaner Production*, *In press*(1), 1–12.

Humphreys, M. (2003). *Development and Structural Investigation of Monocoque Fibre Composite Trusses*.

Hutagalung, M. R. ., LAtif, A. A., & Israr, H. A. (2016). Structural design of UAV semi-monocoque composite wing. *Journal of Transport System Engineering*, *3*(1), 26–34.

İnsuyu, E. T. (2010). *Aero-structural design and analysis of an unmanned aerial vehicle and its mission adaptive wing*. Middle East Technical University.

Iyengar, N., & Gurdal, Z. (1997). Effect of Stacking Sequence on Failure of [45/90/0] Quasi-isotropic Coupons with a Hole Under Compression. *Journal of Thermoplastic Composite Materials*, *10*(2), 136–150.

Jagdale, V., Patil, A., Stanford, B., & Ifju, P. (2009). Conceptual Design of a Bendable UAV Wing Considering Aerodynamic and Structural Performance. In *50th AIAA Structures, Structural Dynamics, and Materials Conference, May 4-7, 2009, Palm Springs, California* (pp. 2641–2650).

James, P., Krishna, D. M., Kotresh, G., & Varughese, B. (2009). Finite Element Analysis of Inter Spar Ribs of Composite Wing of Light Transport Aircraft against Brazier Load. In *National Conference on Scientific Achievements of SC & ST Scientists & Technologists 14–16 April 2009, National Aerospace Laboratories, Bangalore-17* (pp. 57–68).

Jiapeng, T., Ping, X., Baoyuan, Z., & Bifu, H. (2013). A finite element parametric modeling technique of aircraft wing structures. *Chinese Journal of Aeronautics*, *26*(5), 1202–1210.

Johari, H., Henoch, C. W., Custodio, D., & Levshin, A. (2007). Effects of Leading-Edge Protuberances on Airfoil Performance. *AIAA Journal*, *45*(11), 2634–2642.

Jones, L. (1999). *Mechanics of Composite Materials*. *Taylor & Francis*.

Kanesan, G., Mansor, S., & Abdul-Latif, A. (2014). Validation of UAV wing structural model for finite element analysis. *Jurnal Teknologi*, *71*(2), 1–5.

Kavya, G., & Reddy, B. . R. (2015). Design and Finite Element Analysis of Aircraft Wing Using Ribs and Spars. *International Journal and Magazine of Engineering, Technology, Management and Research*, *2*(11), 1443–1455.

Kaw, A. K. (2006). *Mechanics of Composite Materials* (2nd ed.). Florida: Taylor Francis.

Kelly, M., Arora, H., Worley, A., Kaye, M., Linz, P. del, Hopper, P. A., & Dear, J. P. (2016). Sandwich Panel Cores for Blast Applications : Materials and Graded Density. *Experimental Mechanics*, *56*, 523–544.

Koo, V. C., Chan, Y. K., Gobi, V., Chua, M. Y., Lim, C. H., Lim, C.-S., … Sew, B. C. (2012). A New Unmanned Aerial Vehicle Synthetic Aperture Radar for Environmental Monitoring. *Progress In Electromagnetics Research*, *122*, 245–268.

Kotousov, A., & Hui Wang, C. (2002). Fundamental solutions for the generalised plane strain theory. *International Journal of Engineering Science*, *40*(15), 1775–1790.

Kotousov, A., & Tan, P. J. (2004). Effect of the plate thickness on the out-of-plane displacemnet field of a cracked elastic plate loaded in Mode I. *International Journal of Fracture*, *127*(3), L97–L103.

Kumar, A. R., Balakrishnan, S. R., & Balaji, S. (2013). Design Of An Aircraft Wing

Structure For Static Analysis And Fatigue Life Prediction. *International Journal of Engineering Research & Technology (IJERT)*, *2*(5), 1154–1158.
Kumar, T. S. V., Basha, A. W., Pavithra, M., & Srilekha, V. (2015). Static & Dynamic Analysis of a Typical Aircraft Wing Structure Using Msc Nastran. *International Journal of Research in Aeronautical and Mechanical Engineering*, *3*(8), 1–12.
Kunz, P. J. (2003). *Aerodynamics and design for ultra-low Reynolds number flight*. Standford University.
Landolfo, G. (2008). *Aerodynamic and Structural Design of a Small Nonplanar Wing UAV*. *MSc Dissertation*. University of Dayton.
Lau, A. S. H., Haeri, S., & Kim, J. W. (2013). The effect of wavy leading edges on aerofoil-gust interaction noise. *Journal of Sound and Vibration*, *332*(24), 6234–6253.
Lee, Y. T., Pennington, A. de, & Shaw, N. K. (1984). Automatic Finite-Element Mesh Generation from Geometric Models—A Point-Based Approach. *ACM Transactions on Graphics (TOG)*, *3*(4), 287–311.
Levshin, A., Custodio, D., Henoch, C., & Johari, H. (2006). Effects of leading-edge protuberances on airfoil performance. In *Proceedings of the 36th AIAA Fluid Dynamics Conference and Exhibit, June 5-8, 2006, San Francisco, California* (pp. 2868–2883). San Francisco, California: AIAA.
Ling, A. E. (2012). *Design and Manufacturing of Generic Unmanned Aerial Vehicle Fuselage Assembly (Payload bay, empennage, wheel assembly and wingbox) via Low Cost Fiber Glass Molding Process*. *B.Sc Dissertation*. Universiti Tunku Abdul Rahman.
Long, T., Liu, L., Wang, J., Zhou, S., & Meng, L. (2008). Multi-objective Multidisciplinary Optimization of Long-Endurance UAV Wing Using Surrogate Models in ModelCenter. In *12th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference* (pp. 1–8). Canada.
Lopes, J. C. O. (2008). Material Selection for Aeronautical Structural Application. *Material Selection*, *20*, 78–82.
Ma, W., & Feichtinger, K. (2017). Rigid structural foam and foam-cored sandwich composites. In S.-T. Lee (Ed.), *Polymeric foams: Innovations in processes, technologies and products* (Volume 6, pp. 698–846). Boca Raton, FL: CRC Press, taylor & Francis group.
Mailen, R. (2007). *Structural and Manufacturing Analysis for Meridian UAV Wing Concept*. Lawrence, KS 66045-7612.
Mantari, J. L., & Canales, F. G. (2016). Finite element formulation of laminated beams with capability to model the thickness expansion. *Composites Part B*, *101*, 107–115.
Mazhar, F., & Khan, A. M. (2010). Structural Design of a UAV Wing Using Finite Element Method. In *51st AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, April,12 - 15, 2010, Orlando, FLorida* (pp. 3099–3110). Orlando, FLorida.
Mazumdar, S. (2002). *Composites manufacturing: Materials, product and process engineering* (1st ed.). Boca Raton, FL: Taylor & Francis Group.
Mehta, F., & Joshi, H. (2016). Finite Element Method: An Overview. *IOSR Journal of Dental and Medical Sciences*, *15*(3), 38–41.
Miklosovic, D. S., Murray, M. M., & Howle, L. E. (2007). Experimental evaluation of sinusoidal leading edges. *Journal of Aircraft*, *44*(4), 1404–1407.
Miklosovic, D. S., Murray, M. M., Howle, L. E., & Fish, F. E. (2004). Leading-edge tubercles delay stall on humpback whale (Megaptera novaeangliae)

flippers. *Physics of Fluids*, *16*(5), 38–42.
Moon, S. K., Tan, Y. E., Hwang, J., & Yoon, Y. J. (2014). Application of 3D printing technology for designing light-weight unmanned aerial vehicle wing structures. *International Journal of Precision Engineering and Manufacturing - Green Technology*, *1*(3), 223–228.
Naqvi, M. A., Abbas, A., Shah, H. R., & Hamid, M. (2015). Nature Inspired Flying Vehicles and Future Challenges in Aerospace. *International Journal of Automotive Engineering and Technologies*, *4*(1), 40–53.
NASA. (1990). *Design and Manufacturing Guideline for Aerospace Composites*. *Marshall Space Flight Center*.
Nettles, A. T. (1994). Mechanics of laminated composites. In *NASA Reference Publication: Basic Mechanics of Laminated Composite Plates* (pp. 11–23). Washington, DC: National Aeronautics and Space Administration.
Norberg, U. M. (2012). *Vertebrate Flight Mechanics, Physiology, Morphology, Ecology and Evolution* (Illustrate). Berlin: Springer-Verlag.
Nurhaniza, M., Ariffin, M. K. A., Ali, A., Mustapha, F., & Noraini, A. W. (2010). Finite element analysis of composites materials for aerospace applications. *IOP Conference Series: Materials Science and Engineering*, *11*(1), 012010(1)-012010 (7).
Ostergaard, M. G., Ibbotson, A. R., Roux, O. Le, & Prior, A. M. (2011). Virtual testing of aircraft structures. *CEAS Aeronautical Journal*, *1*(1–4), 83–103.
Panchagnula, K. K., & Palaniyandi, K. (2018). Drilling on fiber reinforced polymer / nanopolymer composite laminates : a review. *Journal of Material Research and Technology*, *7*(2), 103–202.
Panzera, P. (2014). Advanced composite materials. In *Aviation Maintenance Technician Handbook - Airframe - Volume 2* (Volume 2, pp. 1–58). Oklahoma City: Federal Aviation Administration.
Paradies, R., & Ciresa, P. (2009). Active wing design with integrated flight control using piezoelectric macro fiber composites. *IOP Publishing: Smart Material Structures*, *18*(3), 035010.
Pedro, H. T. C., & Kobayashi, M. H. (2008). Numerical study of stall delay on humpback whale flippers. In *Proceedings of the 46th AIAA Aerospace Sciences Meeting and Exhibit, January 7-10, 2008, Reno, Nevada* (pp. 584–591). Reno, Nevada: AIAA. https://doi.org/10.2514/6.2008-584
Perry, J. (1950). Aircraft Structures. Chapter 3: Wing configurations. In *Aircraft Structures* (1st editio, pp. 322–353). Dover Publications, Inc.
Prabhu, M. S., Raj, J. N., & Vignesh, G. (2015). Optimization of Unmanned Aerial Vehicle Wing. *International Journal of Innovative Science, Engineering & Technology (IJISET)*, *2*(3), 28–34.
Putra, C. A., Moelyadi, M. A., & Julistina, R. (2016). Comparative Study between Schrenk and CFD Analysis for Predicting Lift Distribution along Wing Span of Glider Aircraft. *Advance in Aerospace Science and Technology in Indonesia*, *1*(10), 108–117.
Quan, C., Han, B., Hou, Z., Zhang, Q., Tian, X., & Lu, T. J. (2020). 3D Printed Continuous Fiber Reinforced Composite Auxetic Honeycomb Structures. *Composites Part B: Engineering*, *187*(February), 107858.
Rajagopal, S., & Ganguli, R. (2012). Multidisciplinary design optimization of long endurance unmanned aerial vehicle wing. *Computer Modeling in Engineering & Sciences(CMES)*, *1680*(1), 1–34.
Ramos, M. H. S. (2015a). *Construction and Analysis of a Lightweight UAV Wing Prototype*.

Ramos, M. H. S. (2015b). *Construction and Analysis of a Lightweight UAV Wing Prototype*. Instituto Superior Técnico Lisboa, Portugal.

Rooks, B. (2001). Automatic Wing Box Assembly Developments. *Industrial Robot: An International Journal*, *28*(4), 297–301.

Rowe, J. (2007). *Finite Element Modeling of an Inflatable Wing*. University of Kentucky.

Sachdeva, C., Miglani, J., & Padhee, S. (2016). Stress Development Analysis within Composite Laminate for Different Layup Orientations. In *SAE Technical Papers* (pp. 1–6).

Sadraey, M. (2010). A Systems Engineering Approach to Unmanned Aerial Vehicle Design. In *10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, September 13-15, 2010, Fort Worth, Texas* (pp. 1–23).

Sahin, M., Sankar, L. N., Chandrasekhara, M. S., & Tung, C. (2003). Dynamic Stall Alleviation Using a Deformable Leading Edge Concept-A Numerical Study. *Journal of Aircraft*, *40*(1), 77–85.

Schrenk, O. (1940). A simple approximation method for obtaining the spanwise lift distribution. *The Aeronautical Journal*, *45*(370), 331–336.

Şenelt, E. (2010). *Design and manufacturing of a tactical unmanned air vehicle*. Middle East Technical University.

Serres, N., Tidu, D., Sankare, S., & Hlawka, F. (2011). Environmental comparison of MESO-CLAD process and conventional machining implementing life cycle assessment. *Journal of Cleaner Production*, *19*(9–10), 1117–1124.

Serson, D., & Meneghini, J. R. (2015). Numerical Study of Wings with Wavy Leading and Trailing Edges. *Procedia IUTAM*, *14*(11), 563–569.

Seshagiri, A., Cooper, E., & Traub, L. W. (2009). Effects of vortex geneartors on an airfoil at low Reynolds numbers. *AIAA Journal of Aircraft*, *46*(1), 116–122.

Shabeer, K. ., & Murtaza, M. . (2013). Optimization of Aircraft Wing With Composite Material. *International Journal of Innovative Research in Science, Engineering and Technology*, *2*(6), 2471–2477.

Soemaryanto, A. R., & Rosid, N. H. (2017). Verification of Schrenk Method for Wing Loading Analysis of Small Unmanned Aircraft using Navier-Stokes based CFD Simulation. *Jurnal Teknologi Dirgantara*, *15*(2), 161–166.

Stein, B., & Murray, M. (2005). Stall Mechanism Analysis of Humpback Whale Flipper Models. In *Proceedings of Unmanned Untethered Submersible Technology, August 21-24, 2005, Durham, England* (pp. 1–5). Durham, England: Autonomous Undersea Systems Institute.

Sullivan, R., Rais-Rohani, M., Lacy, T., & Alday, N. (2006). Structural Testing of an Ultralight UAV Composite Wing. In *Proceddings of the 47th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, May 1-4, 2006, Newport, Rhode Island* (pp. 1870–1879). Newport, Rhode Island: AIAA.

Sullivan, R. W., Hwang, Y., Rais-Rohani, M., & Lacy, T. (2009). Structural Analysis and Testing of an Ultralight Unmanned-Aerial-Vehicle Carbon-Composite Wing. *Journal of Aircraft*, *46*(3), 814–820.

Sun, C. ., Quinn, B. J., & Tao, J. (1996). *Comparative Evaluation of Failure Analysis Method for Composite Analysis*.

Swartz, S. M., Iriarte-diaz, J., Riskin, D. K., Song, A., Tian, X., Willis, D. J., & Breuer, K. S. (2007). Wing Structure and the Aerodynamic Basis of Flight

in Bats. *45th AIAA Aerospace Sciences Meeting and Exhibit*. AIAA.
Szabó, B. A., & Babuška, I. (2009). *An Introduction to Finite Element Analysis*.
Taylor, J. R. (1997). *An Introduction to Error Analysis: The Study of Uncertainties in Physical Measurements* (2nd editio). Sausalito, California: University Science Books.
Teresa, S. J. De, & Hoppel, P. R. C. (1999). Effect of an Angle-Ply Orientation ' on Compression Strength of Composite Laminates. *Materials Research*, (June), 1–42.
Tsai, S. W., & Wu, E. M. (1971). Theory of Strength for Anisotropic Materials. *J. Composite Materials*, *5*(1), 58–80.
Turgut, T. (2007). *Manufacturing and structural analysis of a lightweight sandwich composite UAV wing*. Middle East Technical University.
Turner, M. J., Clough, R. ., Martin, H. C., & Topp, L. . (1956). Stiffness and Deflection Analysis of Complex Structures. *Journal Of The Aeronautical Sciences*, *23*(9), 805–827.
Ünlüsoy, L. (2010). *Structural Design and Analysis of the Mission Adaptive Wings of an Unmanned Aerial Vehicle*. *MSc Dissertation*. Middle East Technical University.
Vaidya, R. (2009). *Structural Analysis of Polyethylene Terephthalate Bottles using Finite Element Method*. *Faculty of the Graduate College of the Oklahoma State University*.
Vale, J., Lau, F., Suleman, A., & Gamboa, P. (2006). Multidisciplinary design optimization of a morphing wing for an experimental UAV. In *Proceedings of the 11th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference, September 6-8, 2006, Portsmouth, Virginia* (pp. 7031–7150). Portsmouth, Virginia: AIAA.
Van Nierop, E. A., Alben, S., & Brenner, M. P. (2008). How bumps on whale flippers delay stall: An aerodynamic model. *Physical Review Letters*, *100*(5), 0545021–0545024.
Vasiliev, V. V., & Morozov, E. V. (2001). *Mechanics and Analysis of Composite Materials* (1st ed). Kidling: Elsevier Science Ltd.
Vnuččec, Z. (2005). Analysis of the laminated composite plate under combined loads. In *RIM 2005: 5th International Scientific Conference on Production Engineering* (pp. 143–148).
Watts, P., & Fish, F. E. (2001). The influence of passive, leading edge tubercles on wing performance. In *Proc. Twelfth Intl. Symp. Unmanned Untethered Submers. Technol., Durham New Hampshire* (pp. 2–9). Undersea Syst. Inst.
Weisler, W., Stewart, W., Anderson, M. B., Peters, K. J., Gopalarathnam, A., & Bryant, M. (2017). Testing and Characterization of a Fixed Wing Cross-Domain Unmanned Vehicle Operating in Aerial and Underwater Environments. *IEEE Journal of Oceanic Engineering*, *99*, 1–14.
Xingwei, Z., Chaoying, Z., Tao, Z., & Wenying, J. (2013). Numerical study on effect of leading-edge tubercles. *Aircraft Engineering and Aerospace Technology*, *85*(4), 247–257.
Zhao, W., Muthirevula, N., Kapania, R. K., Gupta, A., Regan, C. D., & Seiler, P. J. (2017). A Subcomponent-based Finite Element Model Updating for a Composite Flying-wing Aircraft. In *AIAA SciTech Forum: AIAA Atmospheric Flight Mechanics Conference* (pp. 1–30). Grapevine, Texas.

BIODATA OF STUDENT

Ernnie Illyani binti Basri was born on 26th November 1989 in Kedah, Malaysia. She has been living in Jitra, Kedah and received her primary schooling from Sekolah Kebangsaan Kepala Batas, Jitra and Sekolah Kebangsaan Hulu Bernam, Selangor. Her secondary school is Sekolah Menengah Kebangsaan Khir Johari, Perak since 2001 to 2004 as she moved to Tanjong Malim, Perak. In 2005 to 2006, she went to a boarding school of Sekolah Berasrama Penuh Integrasi Gopeng in Perak. Besides received outstanding results with flying colours, she has actively participated in various competitions and sports such as sprint run represent school and district, Arabic Language Club as secretary, Petanque, and etc. She also been nominated as “Anugerah Gemilang” for the best Cumulative Grade Point Average for SPM.

Before she pursues her study of bachelor degree in Manufacturing Engineering with Management (Mechanical) in Universiti Sains Malaysia (USM) Nibong Tebal, Penang since 2008 to 20012, she went to Perak Matriculation College in Gopeng, Perak. During her degree, she has been actively joined Perodua Eco-Challenge competition, attachment with Intel Technologies in Vietnam. She also received the Yellow Belt for Lean Six Sigma as well as Dean List Award for several semesters. Since her final year degree, she has been involving with the manufacturing industries attachment. Then she became interested in pursuing her study to master degree in research area. She registered for Master of Science (MSc) in Universiti Sains Malaysia, Penang and her research interest are manufacturing and maintenance systems involving manufacturing industry. With a great experience, attachment to manufacturing company while doing her master study, she received various experience in spreading the knowledge to the industrial practitioners as well as education practitioners. Then, in September 2016, she pursued her study in PhD with research area of fundamental numerical investigations and experiment on aircraft wing. With the knowledge of her degree and master studies, she interested in implementing the manufacturing knowledge which to be embedded in the application of aerospace. She also joined ANSYS Workbench Workshop by CADD centre to gain knowledge regarding simulation. She also actively participate and organizing conference events, known as International Conference on Computational Methods in Engineering and Health Sciences (ICCMEH) for year 2015 in UPM (Malaysia), 2016 in Kyushu Institute of Technology (Japan) and 2019 in UPM (Malaysia). In 2017, she joined Fluid-Structure Interaction (FSI) workshop in USM Engineering Campus. In 2019, she also actively joined “Seminar: Next generation of engineering technology and simulation with ANSYS” in UiTM Shah Alama. During her PhD, she met and married her lovely husband, Adi Azriff bin Basri as her soul mate and who always be with her through thick and thin.

LIST OF PUBLICATIONS

Journal

Ernnie I. Basri, M.T.H. Sultan, Faizal M., Adi A. Basri, Mohd. F. Abas, M.S Abdul Majid, J.S. Mandeep, Kamarul A. Ahmad, (2019), "Performance Analysis of Composite Ply Orientation in Aeronautical Application of Unmanned Aerial Vehicle (UAV) NACA4415 Wing", *Journal of Materials Research and Technology*, 8(5), 3822-3834. [*Q1: 3.327*]

Ernnie I. Basri, M.T.H. Sultan, Faizal M., Adi A. Basri, Mohd. F. Abas, M.S Abdul Majid, J.S. Mandeep, Kamarul A. Ahmad, (2019), "Conceptual Design and Simulation Validation based Finite Element Optimisation for Tubercle Leading Edge Composite Wing of an Unmanned Aerial Vehicle", *Journal of Materials Research and Technology*, 8 (5), 4374-4386. [*Q1: 3.327*]

Ernnie I. Basri, M.T.H. Sultan, Faizal M., Adi A. Basri, Kamarul A. Ahmad, (2019), "Unmanned Aerial Vehicle (UAV) Structural and Manufacturing of Conventional and Humpback Tubercles Leading Edge (TLE) in Aeronautical Applications", *Journal of Recent Technology and Engineering*, 8 (1S5), 479-496. [*Scopus: 0.08*]

Ernnie I. Basri, Adi A. Basri, Mohd. F. Abas, Faizal M., M.T.H. Sultan, Kamarul A. Ahmad, (2019), "UAV NACA4415 Wing Structural Performance Analysis Subjected to External Aerodynamic Loading Using Schrenk's Approximation", *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, 60 (2), 178-190. [*Scopus: 1.09*]

Ernnie I. Basri, Adi A. Basri, Vizy N. Riazuddin, Siti F. Shahwir, Mohamed Zubair, Kamarul A. Ahmad (2016), "Computational Fluid Dynamics Study in Biomedical Applications: A Review", *International Journal of Fluids and Heat Transfer*, 1 (2), 2-14. [*Non-Scopus index*]

N. N. M. Kamal, Adi A. Basri, Ernnie I. Basri, Ida S. Basri, M. F. Abas (2020), "Validation of Schrenk's Approximation Mthod versus Comptational Fluid Dynamics of Aerodynamic Loading on a 3D wing", *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, In press, Corrected proof. [*Scopus: 1.09*]

Aaroh, Mohammad Zuber, Shah Md. Abdul Khader, Sagar Kalburgi, Ernnie I. Basri, Kamarul A. Ahmad (2018), "Performance of a Monarch Butterfly for Various Flapping Angle", *International Journal of Engineering and Technology*, 7 (4.25), 126-130. [*Scopus: 0.08*]

Conference Proceedings

Ernnie I. Basri, Adi A. Basri, Vizy N. Riazuddin, Siti F. Shahwir, Mohamed Zubair, Kamarul A. Ahmad, "Computational Fluid Dynamic in Biomedical Application", International Conference on Computational Method in Engineering and Health Sciences 2015 (ICCMEH 2015), Universiti Putra Malaysia, Malaysia, 19-20 December 2015.

Ernnie I. Basri, Mohamed Zubair, Kamarul A. Ahmad, Masaaki Tamagawa, "Finite Element Analysis of NACA4415 Tubercle Wing", International Conference on Computational Method in Engineering and Health Sciences 2016 (ICCMEH 2016), Kyushu Institute of Technology,Japan, 17-18 December 2016.

Ernnie I. Basri, Mohamed Zubair, Kamarul A. Ahmad, Masaaki Tamagawa, "Finite Element on Conventional and Tubercles Wing", SAES2016, Kyushu Institute of Technology, Japan, 17-18 December 2016.

Aaroh, Mohammad Zuber, Shah Md. Abdul Khader, Sagar Kalburgi, Ernnie I. Basri, Kamarul A. Ahmad, "Performance of a Monarch Butterfly for Various Flapping Angle", International Conference on Aviation Technology and Management (ICATeM), Kuala Lumpur, Malaysia, 12-14 September 2018.

UNIVERSITI PUTRA MALAYSIA

STATUS CONFIRMATION FOR THESIS / PROJECT REPORT AND COPYRIGHT

ACADEMIC SESSION : 2nd semester 2018/2019

TITLE OF THESIS / PROJECT REPORT : NUMERICAL ANALYSIS OF TUBERCLES LEADING EDGE FOR UNMANNED AERIAL VEHICLE (UAV) COMPOSITE WING

NAME OF STUDENT :

ERNNIE ILLYANI BINTI BASRI

I acknowledge that the copyright and other intellectual property in the thesis/project report belonged to Universiti Putra Malaysia and I agree to allow this thesis/project report to be placed at the library under the following terms:

1. This thesis/project report is the property of Universiti Putra Malaysia.

2. The library of Universiti Putra Malaysia has the right to make copies for educational purposes only.

3. The library of Universiti Putra Malaysia is allowed to make copies of this thesis for academic exchange.

I declare that this thesis is classified as:

*Please tick (√)

[ ]	**CONFIDENTIAL**	(Contain confidential information under Official Secret Act 1972).
[ ]	**RESTRICTED**	(Contains restricted information as specified by the organization/institution where research was done).
[/]	**OPEN ACCESS**	I agree that my thesis/project report to be published as hard copy or online open access.

This thesis is submitted for:

☐ **PATENT** Embargo from ____________ until ____________
(date) (date)

Approved by:

____
(Signature of Student)
New IC No/ Passport No.:

Date :

____
(Signature of Chairman
of Supervisory Committee)
Name:

Date :

[Note : If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization/institution with period and reasons for confidentially or restricted.]