

# **INVESTIGATION OF AERODYNAMIC FORCES ON NACA AIRFOILS**

**EMANNUEL CHAI**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**INVESTIGATION OF AERODYNAMIC FORCES ON NACA AIRFOILS**

**EMANNUEL CHAI**

**A report submitted  
In fulfillment of the requirement for the degree of  
Bachelor of Mechanical Engineering**

**Faculty of Mechanical Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2019**

## DECLARATION

I declare that this project entitled “Investigation of Aerodynamic Forces on NACA Airfoils” is the result of my own work except as cited in the references.

Signature : .....

Name : Emmanuel Chai

Date : .....

## **APPROVAL**

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

Signature : .....

Supervisor Name : En.Shamsul Bahari Bin Azraai

Date : .....

## **DEDICATION**

This report is dedicated to En. Shamsul Bahari Bin Azraai for his guidance, inspiration and teaching that I was able to successfully completed it. I also would like to dedicated this to my beloved family for their support and love that encourage me on finishing this project. Last but not least, I would like to dedicate to all of my friends that lend me helping hands and provide supports on this journey of completing this report.

## ABSTRACT

The aim of this project is to investigate the aerodynamic force on NACA airfoils by using Computational Fluid Dynamic simulation. ANSYS FLUENT 16 was used as the software for the CFD simulation of NACA 4412 and NACA 4418 in two different turbulence models which are Spalart-Allmaras (S-A) and Transition Shear Stress Transport (SST). The CFD simulation were done in three different air velocities of 10 m/s, 20 m/s and 30 m/s. The angle of attack of the airfoil also varied from  $0^\circ$  to  $50^\circ$  with increment of  $5^\circ$ . These two airfoils were chosen because both different maximum thickness but have the same mean camber line and maximum camber. The airfoil was designed in Solidworks with chord length of 100 mm. A rectangular domain of 300 mm x 300 mm x 450 mm was chosen as the fluid domain to mimic the experiment in wind tunnel with the same dimension of test section. The results for simulated aerodynamic forces between the two airfoils with two different turbulence models were analysed and discussed. Besides, results for the three different air velocity also analysed and the best angle of attack for the airfoils were determine. From the results, the stall angle for both NACA 4412 and NACA 4418 is at  $45^\circ$  for air velocity of 20 m/s and 30 m/s while the stall angle for both airfoils is  $40^\circ$  at 10 m/s. The effect of thickness of the airfoil on aerodynamic forces was also studied where NACA 4418 generate more lift force at its best angle of attack compare to NACA 4412. The performance for NACA 4418 is better than NACA 4412.

## ABSTRAK

*Tujuan projek ini dijalankan adalah untuk menyiasat daya aerodinamik pada aerofoil NACA dengan menggunakan simulasi “Computational Fluid Dynamic”. ANSYS FLUENT 16 digunakan sebagai perisian untuk simulasi CFD pada NACA 4412 dan NACA 4418 dalam dua model pergolakan yang berbeza iaitu Spalart-Allmaras (S-A) dan Transition Shear Stress Transport (SST). Simulasi CFD dilakukan dalam tiga kelajuan udara yang berbeza iaitu 10 m/s, 20 m/s dan 30 m/s. Sudut serangan airfoil juga diubah dari 0 ° hingga 50° dengan kenaikan 5°. Kedua-dua airfoil ini dipilih kerana kedua-dua ketebalan maksimum yang berbeza tetapi mempunyai purata garis camber yang sama dan camber maksimum. Aerofoil ini direka bentuk dalam Solidworks dengan panjang kord 100mm. Domain segi empat tepat 300 mm x 300 mm x 450 mm dipilih sebagai domain bendalir untuk meniru percubaan ekperimentasi dalam terowong angin dengan dimensi yang sama pada bahagian ujian. Keputusan untuk daya aerodinamik yang disimulasi antara kedua-dua airfoil dengan dua model pergolakan yang berbeza dianalisis dan dibincangkan. Selain itu, keputusan untuk tiga halaju udara yang berbeza juga dianalisis dan sudut serangan yang terbaik untuk airfoil ditentukan pada setiap kelajuan. Hasil dari simulasi, sudut serangan kritikal untuk NACA 4412 dan NACA 4418 adalah pada 45° pada kelajuan udara di 20 m/s dan 30 m/s manakala sudut serangan kritikal untuk kedua-dua airfoil berada pada 40 ° pada kelajuan 10 m/s. Kesan ketebalan aerofoil terhadap daya aerodinamik juga dikaji di mana NACA 4418 menjana daya angkat lebih pada sudut serangan terbaik berbanding dengan NACA 4412. Prestasi untuk NACA 4418 adalah lebih baik daripada NACA 4412.*

## ACKNOWLEDGEMENTS

First and foremost, I would like to give thanks and praises to Almighty God for the blessing and strength that He gave in order for me to fulfill and complete this final year project (FYP).

I would like to express my sincere gratitude to my supervisor, En. Shamsul Bahari Bin Azraai for all of his valuable contribution, guidance, ideas and comments during my journey on finishing this project. Views and opinions from him that allow me to grow and understand more on this project. I also would like to give gratitude to En. Mohd. Hafidzal Bin Mohd. Hanafi and Dr. Md. Isa Bin Ali for their comments and suggestion that help me to improve my project as well as gain more knowledge.

A special thanks to my family members for their love, support and words of encouragement that boost my strength and confidence to complete this project. Besides, I also like say thanks to all my friend that support me throughout this journey that keep me cheerful during tough times. Finally, to everyone who has directly or indirectly contributed to this project, I say thank you as well.



## TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	
	APPROVAL	
	DEDICATION	
	ABSTRACT	i
	ABSTRAK	ii
	ACKNOWLEDGEMENT	iii
	TABLE OF CONTENTS	iv
	LIST OF FIGURES	vii
	LIST OF TABLES	xi
	LIST OF ABBREVIATIONS	xiii
	LIST OF SYMBOLS	xiv
1	INTRODUCTION	
	1.0 Background of Study	1
	1.1 Problem Statements	4
	1.2 Objective	5
	1.3 Scope of Study	6
	1.4 General Methodology	6

<b>2</b>	<b>LITERATURE REVIEW</b>	
2.0	Introduction	8
2.1	Theory on Aerodynamic Forces and Mathematic Modelling	8
2.1.1	Fluid Flow	8
2.1.2	Lift and Drag Forces	11
2.1.3	Reynolds Number	12
2.2	Applications of Airfoils	12
2.3	Approach in Investigation of Aerodynamic Force on Airfoil	14
2.3.1	Experimental Investigation on Airfoil	14
2.3.2	Numerical Investigation on Airfoil	16
2.3.3	Numerical and Experimental Investigation on Airfoil	16
<b>3</b>	<b>METHODOLOGY</b>	
3.0	Introduction	19
3.1	Modelling Airfoils Geometry in Solidworks 2017	21
3.2	Importing Geometry into DesignModeler	24
3.3	Meshing	24
3.4	Setup for Simulation	26
3.5	Post-Processing	26
<b>4</b>	<b>RESULTS AND DISCUSSION</b>	
4.0	Introduction	28

4.1	Aerodynamic Forces on NACA 4412 and NACA 4418	28
4.1.1	Lift Force on NACA 4412	29
4.1.2	Drag Force on NACA 4412	32
4.1.3	Lift Force on NACA 4418	35
4.1.4	Drag Force on NACA 4418	38
4.2	Comparison Between Results Obtained From S-A Model and Transition SST Model for NACA 4412	41
4.3	Comparison Between Results Obtained From S-A Model and Transition SST Model for NACA 4418	42
4.4	Aerodynamic Forces Comparison Between NACA 4412 and NACA 4418	43
4.5	Visualization of Simulated Airfoils Using Contours	46 52
4.6	Validation of Data	
<b>5</b>	<b>CONCLUSION AND RECOMMENDATION</b>	
5.0	Conclusion	55
5.1	Recommendation	56
	<b>REFERANCES</b>	57
	<b>APPENDICES</b>	59

## LIST OF FIGURES

FIGURE	TITLE	PAGE
1.1	An airfoil geometry profile. (Source : <a href="https://en.wikipedia.org/wiki/Airfoil">https://en.wikipedia.org/wiki/Airfoil</a> )	1
1.2	Forces components on an airfoil.	3
1.3	Flow chart of the general methodology	7
2.1	Viscous flow regions and inviscid flow regions on fluid flow over a flat plate. (Cengel & Cimbala, 2009)	9
2.2	Image of laminar, transitional and turbulent flows. (Cengel & Cimbala, 2009)	11
2.3	Lift coefficient versus angle of attack (Ahmad Khairuddin, 2008)	17
2.4	Aerodynamic force obtained by simulation using Transition SST model at 20 m/s by Lim (2009)	18
3.1	Planned flow for CFD simulation.	20
3.2	Coordinate of NACA 4412 airfoil (Left) and NACA 4418 (Right).	22
3.3	3-D Model of NACA 4412 drawn in Solidworks.	23
3.4	3-D Model of NACA 4418 drawn in Solidworks.	23
3.5	Number of nodes, elements and skewness for NACA 4412 at 0°	25
3.6	Meshing done airfoil and the fluid domain	25

3.7	Aerodynamic forces on NACA 4418 at air velocity of 20 m/s and angle of attack of 10° using Transition SST model	27
3.8	Aerodynamic forces on NACA 4412 at air velocity of 30 m/s and angle of attack of 50° using S-A model	27
4.1	Graph of lift force of NACA 4412 using S-A model against different angle of attack at 10 m/s	29
4.2	Graph of lift force of NACA 4412 using SST model against different angle of attack at 10 m/s	29
4.3	Graph of lift force of NACA 4412 against different angle of attack for S-A Model	31
4.4	Graph of lift force of NACA 4412 against different angle of attack for Transition SST Model	32
4.5	Graph of drag force of NACA 4412 using S-A model against different angle of attack at 10 m/s	32
4.6	Graph of drag force of NACA 4412 using Transition SST model against different angle of attack at 10 m/s	33
4.7	Graph of drag force of NACA 4412 against at three different speed and angle of attack for S-A model	34
4.8	Graph of drag force of NACA 4412 against at three different speed and angle of attack for Transition SST model	35
4.9	Graph of lift force of NACA 4418 using S-A model against different angle of attack at 10 m/s	35
4.10	Graph of lift force of NACA 4418 using Transition SST model against different angle of attack at 10 m/s	36
4.11	Graph of lift force of NACA 4418 against different angle of attack for S-A Model	37

4.12	Graph of lift force of NACA 4418 against different angle of attack for Transition SST Model	38
4.13	Graph of drag force of NACA 4418 using S-A model against different angle of attack at 10 m/s	38
4.14	Graph of drag force of NACA 4418 using Transition SST model against different angle of attack at 10 m/s	39
4.15	Graph of drag force of NACA 4418 using S-A model at three different air velocity	40
4.16	Graph of drag force of NACA 4418 using Transition SST model at three different air velocity	40
4.17	Graph of lift force against different angle of attack for S-A and Transition SST Model	41
4.18	Graph of drag force against different angle of attack for S-A and Transition SST Model	42
4.19	Graph of lift force against different angle of attack for S-A and SST Model	42
4.20	Graph of drag force against different angle of attack for S-A and SST Model	43
4.21	Graph of lift force against angle of attack at 30 m/s between NACA 4412 and NACA 4418	44
4.22	Graph of drag force against angle of attack at 30 m/s between NACA 4412 and NACA 4418	45
4.23	Pressure contour at angle of attack, 0°	46
4.24	Velocity contour at angle of attack, 0°	47
4.25	Velocity vector at angle of attack, 0°	47

4.26	Pressure contour at angle of attack, 20°	48
4.27	Velocity contour at angle of attack, 20°	48
4.28	Velocity vector at angle of attack, 20°	49
4.29	Pressure contour at angle of attack, 50°	49
4.30	Velocity contour at angle of attack, 50°	50
4.31	Velocity vector at angle of attack, 50°	51
4.32	Comparison between lift force obtained through simulation with Lim (2009)	52
4.33	Comparison between drag force obtained through simulation with Lim (2009)	53

## LIST OF TABLES

TABLE	TITLE	PAGE
3.1	Details of test for the CFD simulations.	19
A.1	Properties of air at 1 atm pressure. (Cengel & Boles, 2015)	59
B.1	US Standard Atmosphere Air Properties – SI Units  (Source: <a href="https://www.engineeringtoolbox.com/standard-atmosphere-d_604.html">https://www.engineeringtoolbox.com/standard-atmosphere-d_604.html</a> )	60
B.2	Table B.2: Linear interpolation.	61
C.1	Gantt chart for PSM I	63
C.2	Gantt chart for PSM II	64
D.1	Results for NACA 4412 at 10 m/s using S-A Model	65
D.2	Results for NACA 4412 at 20 m/s using S-A Model	65
D.3	Results for NACA 4412 at 30 m/s using S-A Model	66
D.4	Results for NACA 4412 at 10 m/s using SST Model	66
D.5	Results for NACA 4412 at 20 m/s using SST Model	67
D.6	Results for NACA 4412 at 30 m/s using SST Model	67
E.1	Results for NACA 4418 at 10 m/s using S-A Model	68
E.2	Results for NACA 4418 at 20 m/s using S-A Model	68
E.3	Results for NACA 4418 at 30 m/s using S-A Model	69



E.4	Results for NACA 4418 at 10 m/s using SST Model	69
E.5	Results for NACA 4418 at 20 m/s using SST Model	70
E.6	Results for NACA 4418 at 30 m/s using SST Model	70

## LIST OF ABBREVIATIONS

NACA	=	National Advisory Committee for Aeronautics
CFD	=	Computational Fluid Dynamic
3-D	=	3-Dimensional
S-A	=	Spalart-Allmaras
SST	=	Shear Stress Transport
FKM	=	Fakulti Kejuruteraan Mekanikal @ Faculty of Mechanical Engineering
UTeM	=	Universiti Teknikal Malaysia Melaka

## LIST OF SYMBOLS

$\alpha$	=	Angle of attack
$x_0, y_0, z_0$	=	Fixed point in the fluid field
$V$	=	Upstream velocity (m/s)
$P$	=	Pressure (Pa)
$t$	=	Time (s)
$Ma$	=	Mach Number
$F_D$	=	Drag force (N)
$F_L$	=	Lift force (N)
$\rho$	=	Density (kg/m <sup>3</sup> )
$C_D$	=	Coefficient of drag
$C_L$	=	Coefficient of lift
$Re$	=	Reynolds Number
$L_c$	=	Chord length of airfoil (m)
$\mu$	=	Dynamic viscosity of fluid (kg/m.s)
$\nu$	=	Kinematic viscosity of fluid (m <sup>2</sup> /s)
$H$	=	Altitude (m)
$T$	=	Temperature (°C)

# CHAPTER 1

## INTRODUCTION

### 1.0 Background of Study

An airfoil is defined as the cross section of a body that is placed in an airstream to produce a useful aerodynamic force in the most efficient manner possible. (E. Abrahams & D. Cladwell, 2005) The airfoil profile geometry is shown in Figure 1.1. The important aspects of the airfoil geometry are the maximum camber, chord and the maximum thickness where it is used for classification of an airfoil. The length of the chord line that connecting the leading and trailing edges is called chord. Leading edge is the point at front of the airfoil that has maximum curvature whereas the trailing edge is the point has maximum curvature as well but at the rear area of the airfoil. The maximum camber line is the distance between the mean camber line and the chord. The thickest part of the airfoil is the maximum thickness.

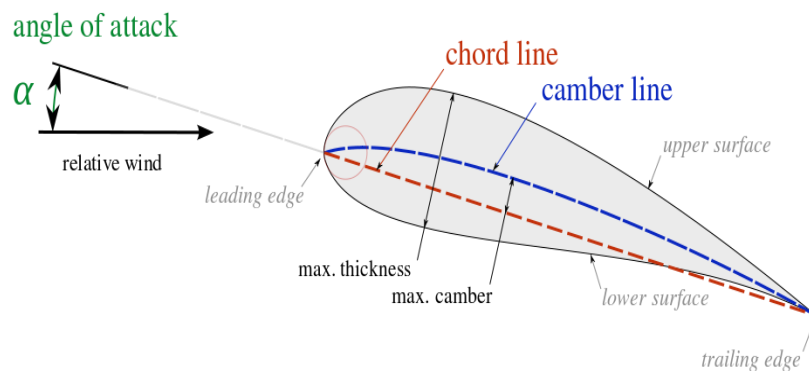


Figure 1.1: An airfoil geometry profile. (Source: <https://en.wikipedia.org/wiki/Airfoil>)

One of the common and known airfoils throughout the world of aviation is NACA airfoil. NACA airfoils are series of airfoils developed by the National Advisory Committee for Aeronautics (NACA); hence, the name given to the airfoils. NACA has standardized the group of airfoils into 4-digit, 5-digit and 6-digit series and the meaning of this nomenclature are best explained by examples.

#### NACA 2412

2 → The mean line has a camber of 0.02 chord; mean line has 4 % camber

4 → The maximum camber located at 0.4 chord

12 → The maximum thickness is 0.12 chord, airfoil has 12% thickness

#### NACA 23012

2 → The mean chamber line has a camber of 0.02 chord approximately

30 → The maximum camber is located at  $0.3/2 = 0.15$  chord

12 → The maximum thickness is 0.12 chord

#### NACA 65<sub>3</sub> - 418

6 → Series designation

5 → The minimum pressure point is at 0.5 chord

3 → The minimum drag coefficient occurs at an angle of attack that corresponds to the design lift coefficient and the bucket-like shape of drag curve (drag bucket) stretches from design lift coefficient of -0.3 to +0.3

3 → design lift coefficient is 0.4

18 → The maximum thickness is 0.18 chord

These are the primary airfoils' series that introduced by the NACA but this does not include the modified series and the airfoils used for supersonic flight. All airfoils have their own unique flight characteristics so the factor of choosing an airfoil usually depends on the requirement for the experiment or manufacturers of the aircraft wings and turbines. Yeminici O. (2014) chose NACA 0012 for his study because of the symmetrical shape of NACA 0012. Kamas T. (2009) chooses the symmetrical NACA 0012 and the cambered NACA 2414 in his study the aerodynamic forces effect on those airfoils.

Aerodynamic forces are forces exerted on a body by the air where the body is immersed in air and it is due to the flow between the body and the gas. When airflow through an airfoil, aerodynamic forces are created caused by normal force and shear force. The normal force is due to the pressure surrounding the airfoil and the skin friction due to the viscosity of the air. The aerodynamic forces in an airfoil can be resolved into three different components with the addition of weight as shown in Figure 1.2. Weight is not considered as an aerodynamic force but a body force since it is caused by gravity and not exerted on the body by air. The lift force is the component of the force that is perpendicular to the flow direction of air while drag force is parallel to the direction of the air flow. Drag is the force that resists the motion of an aircraft during flight. Thrust is the forward force created by the jet engines or propellers to overcome the drag force and thus it acts in the opposite direction of drag force.

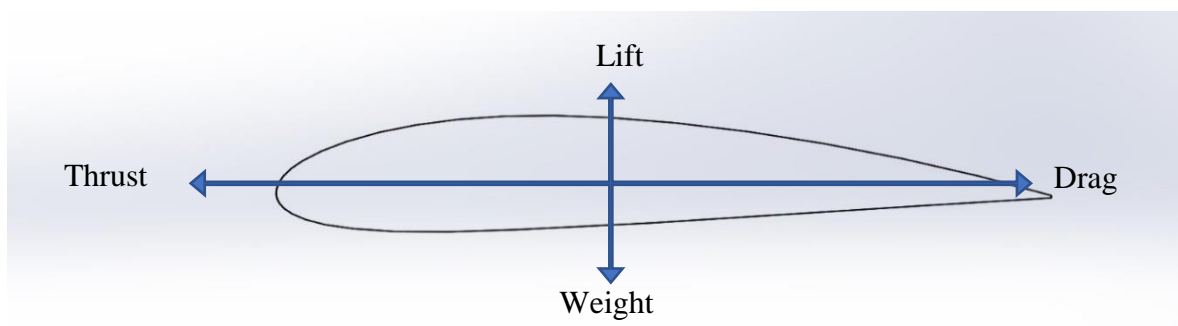


Figure 1.2: Forces components on an airfoil.

An airfoil is designed in a way that the shape takes advantage of the air to react to certain laws of physics. A positive pressure lifting action occurs at the lower surface of the airfoil and a negative pressure lifting action from lowered pressure on the top surface occurs as the air strikes the airfoil. In an aircraft flight or in a wind tunnel, an airfoil is a streamlined object that is placed into an airstream movement. For the airfoil to lift, the air moving over the upper surface must move faster than the air moving along the lower surface. This is done by inclining the airfoil to a certain angle so that the airflow becomes faster at the upper surface. The increase in speed on the upper surface of the airfoil produces a drop in pressure according to Bernoulli's principle. This will cause differences in pressure on upper and lower surfaces. The higher pressure on the lower surface will push the airfoil upward and thus create lift force.

## **1.1 Problem Statement**

Fuel consumption in an airplane is the major problem for the airline companies and aircraft manufacturers. Koppula, R (2018) stated that it has been estimated that fuel demands from aviation will increase by between 1.9% and 2.6% each year until 2025. This means that more money will be spent on the fuel for the aircraft to operate. Most airline companies and aircraft manufacturers want to reduce the amount of money spent on fuel consumption of aircraft. Fuel consumption can be related to the drag produced by the aircraft during flight. If the drag produced by the aircraft is high, the fuel consumption also increases.

This is because the thrust needed to overcome the drag is produced by the engines of the aircraft. The engines use fuel to power up, thus the drag indirectly increases the fuel consumption. Payloads of the aircraft also play an important role in fuel consumption but in this study, the concern is more toward reducing the drag to increase the efficiency of fuel

consumption. Reducing drag means that study on airfoils essential for correct selection of airfoils needed to design the wing, winglet and the tail plane.

Haque M. N., et al. (2015) stated that the efficiency, as well as the performance of an aircraft mostly depend on the aerodynamic characteristics e.g. lift, drag, lift to drag ratio, etc. of wings. Therefore, improving the aerodynamic characteristics are desired by the aircraft manufacturers and racing cars company. Airfoils geometry such as the maximum thickness and maximum camber can play an important role in order to improve the aerodynamic forces. The different in geometry might able to generate significant lift or reducing drag that can improve the aerodynamic performance of the airfoils before selecting it for use of aircraft or the geometry able to help to increase the down force for racing car to increase it speed.

An aerodynamic stall also a concern when flying an airplane. An aerodynamic stall is a condition when the airfoil exceeds its critical angle of attack and cannot produce the desired lift force for the flight. An aerodynamic stall can cause a sudden change in the airplane level where it feels like the airplane is falling. Besides, it also can cause the airplane to roll or turn to one side of the airplane. It a dangerous condition since aircraft may enter a spin and the pilot lose control of the airplane. Therefore, knowing the critical angle of an airfoil is important when designing the aircraft's wings, horizontal and vertical stabilizers.

## **1.2 Objectives**

- i. Comparing the aerodynamic forces between two different NACA airfoil on Computational Fluid Dynamic (CFD) simulation with different turbulent models.
- ii. Analyze the best angle of attack on the airfoils at different velocities