# INVESTIGATION OF AERODYNAMIC FORCES ON NACA AIRFOILS

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**INVESTIGATION OF AERODYNAMIC FORCES ON NACA AIRFOILS**

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**In fulfillment of the requirement for the degree of**
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## 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 | : Emannuel 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° to 50° with increment of 5°. 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° for air velocity of 20 m/s and 30 m/s while the stall angle for both airfoils is 40° 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.*

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## 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$^3$) |
| $C_D$ | = | 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$^2$/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.

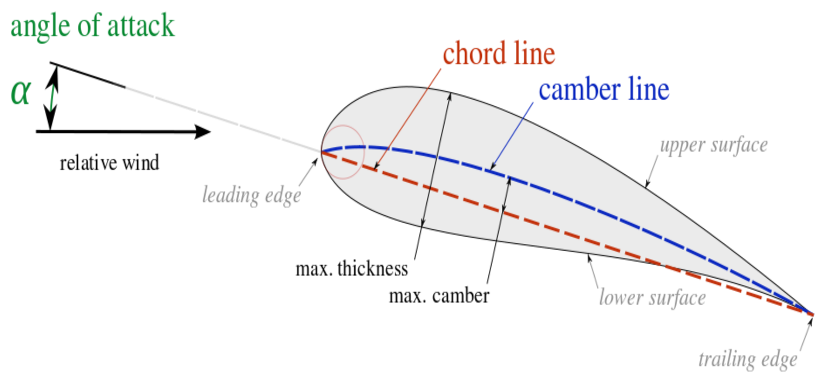


Figure 1.1: An airfoil geometry profile. (Source: https://en.wikipedia.org/wiki/Airfoil)

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 $65_3$ - 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 introduce by the NACA but this does not include the modified series and the airfoils used for supersonic flight. All airfoil has their own unique flight characteristics so the factor of choosing airfoil usually depends on the requirement for the experiment or manufacturers of the aircraft wings and turbines. Yeminici O. (2014) choose 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 causes 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 causes 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.

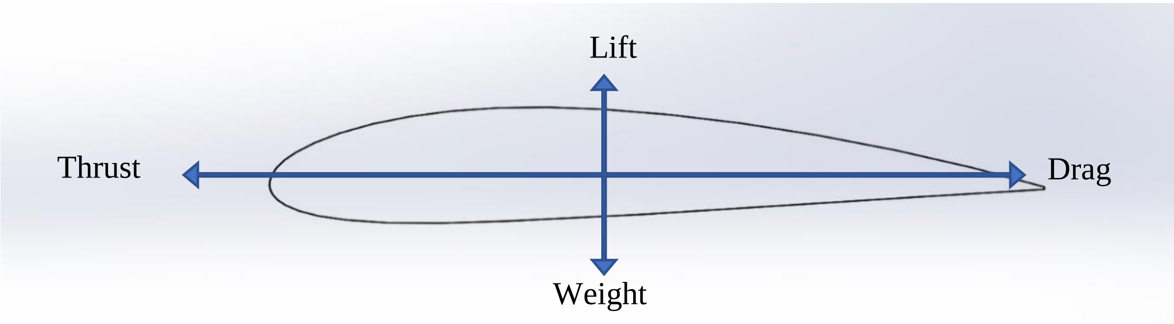


Figure 1.2: Forces components on an airfoil.

An airfoil is designed in a way that the shape takes advantage of the airs to react to certain laws of physic. 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 occur as the air strike the airfoil. In an aircraft flight or in a wind tunnel, an airfoil is a streamlined object that 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 inclined 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 surface. The higher pressure on the lower surface will push the airfoil upward and thus creating 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 manufacturer want to reduce the amount of money spend 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 high, the fuel consumption also increases.

This is because of the thrust needed to overcome the drag is produced by the engines of the aircraft. The engines used fuel to power up thus the drag indirectly increased 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