AERODYNAMIC STUDY OF SYMMETRICAL AND ASYMMETRICAL AIRFOIL IN VARYING ANGLE OF ATTACK AIRFLOWS

SHARIFAH NUR NADIAH SYED YASSIN

THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF BACHELOR OF MECHANICAL ENGINEERING

FACULTY OF ENGINEERING
UNIVERSITI MALAYSIA SABAH

2022

DECLARATION

I thus declare that this thesis, which was submitted to University Malaysia Sabah as part of the requirements for the Bachelor of Mechanical Engineering degree, has not been submitted for a degree to any other university. Except for quotations and summaries of sources that have been properly recognized, I further attest that the work described above is entirely my own.

1ST JULY 2022

SHARIFAH NUR NADIAH

(BK18110184)

CERTIFIED BY

DR. WAN KHAIRUL MUZAMMIL BIN ABDUL RAHIM

SUPERVISOR

CERTIFICATE

NAME : **SHARIFAH NUR NADIAH BINTI SYED YASSIN**

MATRIC NO : **BK18110184**

TITLE : **AERODYNAMIC STUDY OF SYMMETRICAL AND ASYMMETRICAL AIRFOIL VARYING ANGLE OF ATTACK AIRFLOWS**

DEGREE : **BACHELOR OF ENGINEERING WITH HONOUR (MECHANICAL ENGINEERING)**

VIVA DATE : **25TH JULY 2022**

CERTIFIED BY

SUPERVISOR	SIGNATURE
DR WAN KHAIRUL MUZAMMIL BIN ABDUL RAHIM	

UNIVERSITI MALAYSIA SABAH

ACKNOWLEDGEMENT

In the name of Allah, the Most Merciful and Gracious. All praise and blessings to Allah for the successful completion of this thesis. I am grateful to God for all of the opportunities, hardships, and strength that have been bestowed upon me in order to complete the thesis. During this process, I gained a great deal of knowledge and experience, both academically and personally. My humblest gratitude to the holy Prophet Muhammad (Peace be upon him) whose way of life has been a continuous guidance for me.

First and foremost, I would like to sincerely thank my supervisor Dr Wan Khairul Muzammil for his guidance, understanding, patience and most importantly, he has provided positive encouragement and a warm spirit to finish this thesis. It has been a great pleasure and honor to have him as my supervisor.

My deepest gratitude goes to all my family members. It would not be possible to write this thesis without the support from them. I would like to thank my mother Puan Huszailina for her ongoing love and support. To my late father who was often in my thoughts on this journey and could not see this thesis completed, thank you for showing me that the key to success is not to give up – you are missed.

I would sincerely like to thank all my beloved friends who were with me and support me through thick and thin. To everyone, you should know that your support and encouragement was worth more than I can express on paper.

ABSTRACT

An aerodynamic study of symmetrical and asymmetrical airfoil in varying angle of attack of airflows was conducted. In the last decade, wind turbine technology has advanced quickly. Wind power is a well-proven and cost-effective technology that is expected to be the primary means by which industry reacts to the government's aims, resulting in it becoming a significant source of electricity in the coming years. The focused in this study are to carry out a selection process of high lift-to-drag ratio airfoils based on the NACA 4 series using the QBlade software, to develop an experimental method of using a particle image velocimetry (PIV) system integrated with various airfoils, and to investigate the aerodynamic characteristics of symmetrical and asymmetrical airfoil blades in orthogonal fluid flow in the PIV system. The coefficient of drag, C_D and coefficient of lift, C_L values have an impact on airfoil properties C_L. The value of C_D determines the amount of airfoil friction with the air, whereas the value of C_L impacts the amount of lifting force produced by the airfoil. To obtain the best angle of attack, AOA, the design output requires the most ideal C_D and C_L values. This paper also discusses the software and its modules in theory and application at their current condition. QBlade can now be used as a complete wind turbine design tool because of the new capability. QBlade is updated, validated, and enhanced with new features on a regular basis. The viscous-inviscid coupled panel method algorithm XFOIL is integrated within the graphical user interface of QBlade for the construction of custom airfoils and the computation of airfoil lift-and drag coefficient polars.

ABSTRAK

Kajian aerodinamik ke atas airfoil simetri dan asimetri dalam pelbagai sudut aliran udara telah dijalankan. Dalam dekad yang lalu, teknologi turbin angin telah maju dengan pantas. Tenaga angin ialah teknologi yang terbukti dengan baik dan menjimatkan kos yang dijangka menjadi cara utama industri bertindak balas terhadap matlamat kerajaan, menyebabkan ia menjadi sumber elektrik yang penting pada tahun-tahun akan datang. Fokus dalam kajian ini adalah untuk menjalankan proses pemilihan airfoil nisbah angkat-ke-seret yang tinggi berdasarkan siri NACA 4 menggunakan perisian QBlade, untuk membangunkan kaedah eksperimen menggunakan sistem halaju imej zarah (PIV) yang disepadukan dengan pelbagai airfoil, dan untuk menyiasat ciri aerodinamik bilah airfoil simetri dan asimetri dalam aliran bendalir ortogon dalam sistem PIV. Pekali seret, C_D dan pekali daya angkat, nilai C_L mempunyai kesan ke atas sifat airfoil C_L. Nilai C_D menentukan jumlah geseran airfoil dengan udara, manakala nilai C_L memberi kesan kepada jumlah daya angkat yang dihasilkan oleh airfoil. Untuk mendapatkan sudut serangan terbaik, AOA, output reka bentuk memerlukan nilai C_D dan C_L yang paling ideal. Kertas kerja ini juga membincangkan perisian dan modulnya secara teori dan aplikasi pada keadaan semasanya. QBlade kini boleh digunakan sebagai alat reka bentuk turbin angin yang lengkap kerana keupayaan baharu itu. QBlade dikemas kini, disahkan dan dipertingkatkan dengan ciri baharu secara tetap. Algoritma kaedah panel berganding likat-inviscid XFOIL disepadukan dalam antara muka pengguna grafik QBlade untuk pembinaan airfoil tersuai dan pengiraan kutub pekali lif dan seretan airfoil.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

α	Angle of attack
F	Force
Re	Reynolds Number
ρ	Density of the fluid
u	Average velocity
L	Distance
μ	Dynamic viscosity of the fluid.

LIST OF ABBREVIATIONS

NACA	National Advisory Committee of Aeronautics
NASA	National Aeronautics and Space Administration
HAWT	Horizontal Axis Wind Turbine
VAWT	Vertical Axis Wind Turbine
CAD	Computer Aided Design
CFD	Computation Fluid Dynamics
2D	Two Dimensional
3D	Three Dimensional
C_L	Lift coefficient
C_D	Drag coefficient
LTD	Lift-to-drag

CHAPTER 1

INTRODUCTION

1.1 Overview

Global concerns about sustainable growth and development have centred on energy supply and demand imbalances. The need to power the expected and projected development plan relies on availability and access to modern power sources. However, sustainability in the growth process requires that the energy resources be clean and environmentally friendly (Francis et al., 2021). Aerodynamic science concentrates on the use of air as the working media when it passes through any object. An aerodynamic force is created when a body shaped like an airfoil moves through a fluid. Lift is the term for the portion of this force that is perpendicular to the direction of motion. Drag is the element that is perpendicular to the direction of motion. Lift and drag forces on an airfoil blade or wing are known to depend mainly on the airfoil geometry in addition to the angle of attack. The area of cross-section of the wing is known as the airfoil. Blade airfoil profiles are divided into two categories which are symmetric and asymmetric airfoil. It is known that a symmetrical airfoil has a lower lift-to-drag ratio compared to an asymmetrical airfoil.

The airfoil has been the centre of investigations in the field of aerodynamics since the 18th century, but still, lots of research is going on. National Advisory Committee of Aeronautics (NACA) contributes a lot in this field. Sir Isaac Newton was considered the first aero dynamist of the modern world because of his famous publication; Principia. Sir George Cayley gave four fundamentals of flight of any object, i.e., lift, weight, drag, and thrust. A wind turbine is a wind energy conversion device. According to the wind turbine main shaft and the relative position of the ground, the wind turbine can be divided into wind turbines with the horizontal axis and vertical axis wind turbines. Relative to the horizontal axis wind turbine, the vertical axis wind machine has the diversity of wind, no drift, simple structure, low manufacturing, and running cost advantages (Zhao & Liu, 2014). This study investigates the aerodynamics of symmetrical and asymmetrical airfoils to improve the vertical axis wind turbine performance. Therefore, by varying the angle of attack of wind flows (i.e., the angle of the oncoming wind relative to the airfoil position), the aerodynamic investigations could better understand the lift and drag forces of those airfoils.

The airfoil investigation in this study was done with the help of software, targeting specific Reynolds numbers. The flow on this airfoil was analysed for different angles of attack and compared to experimental data for different Reynolds numbers. In this way, many different airfoil shapes could be analysed quickly without experiments. However, validation studies must be carried out to verify the results from the models used in the software.

1.2 Problem Statement

Renewable energy can play an important role. By using renewable energy, it can help to reduce environmental problems. Airfoil shape plays a crucial role in the overall performance of aerodynamic bodies, resulting in extensive research. Atmospheric turbulence is unpredictable and is often subjected to change; therefore, the assessment of aerodynamic characteristics of airfoils under turbulence in the wind tunnel is of primary importance in the field of aerodynamics and wind engineering (Arunvinthan & Nadaraja Pillai, 2019).

Drag is the cost of obtaining a lift. The lift-to-drag (LTD) ratio is the ratio of lift-to-drag created by a wing or airfoil. The lift-to-drag ratio is calculated by dividing the lift coefficient by the drag coefficient, C_L/C_D, to express the relationship between lift and drag. The LTD ratio indicates the efficiency of an airfoil. The shape of an airfoil and other lift-producing devices (such as flaps) influence lift production, which varies when the Angle of Attack (AOA) changes. The maximum LTD ratio can occur at a given lift coefficient, C_L and AOA, which would be an essential point for the current study to look into, depending on the airfoil shape.

The wind conditions in Malaysia are unreliable and unpredictable. The wind velocity is light, calm, and multi directions with an average velocity of 0.3 m/s, which are unsuitable as an alternative energy source even to naturally ventilated indoor spaces (Khalid et al., 2018). Therefore, a study of symmetrical and asymmetrical airfoils that look into their characteristics must be carried out. The study would look into the physical characteristics of airfoils to determine which airfoil has a low LTD ratio or high LTD ratio. This would help develop a better wind turbine that can work in low wind speed conditions, such as Malaysia.

1.3 Research Objective

The research study has carried out with the following objectives:

i. To carry out a selection process of high lift-to-drag ratio airfoils based on the NACA 4 series using the QBlade software.
ii. To develop an experimental method of using a particle image velocimetry (PIV) system integrated with various airfoils.
iii. To investigate the aerodynamic characteristics of symmetrical and asymmetrical airfoil blades in orthogonal fluid flow in the PIV system.

1.4 Scope of Work

The scope of work for the current study is described as follows:

i. Carry out the literature review on the existing and past database of lift-to-drag (LTD) ratios for airfoils used in vertical axis wind turbines (VAWT) from different sources (i.e. journals, books, and articles).
ii. Identify the appropriate NACA series that can be used for the study. In this case, the NACA four-series was chosen due to its flexibility and widely available data from past research.
iii. Classify the high, medium, to a low lift-to-drag ratio of airfoils using the QBlade software. Qblade software is open-source software that deals with an aerodynamic analysis to select airfoils used in the study. The modelling of the 2D airfoils will be carried out using the QBlade software.
iv. The step to validate the QBlade software will be carried out by comparing the software output data from the previous experimental studies. This step is to verify that the QBlade software can be used for further analyses of different airfoils, especially the ones without the availability of experimental data.
v. Next, after filtering the airfoils based on their aerodynamic characteristics, the PIV system's experimental analysis will be carried

out for further investigations. Therefore, there is a need to use the physical model of airfoils. A mounting system is required to fix the airfoil blades in place. The fabrication of this mounting system will be carried out using a 3D printer.

vi. The lift and drag forces will be measured over the surfaces of the symmetrical and asymmetrical airfoils based on the extracted PIV data.

1.5 Project Flowchart

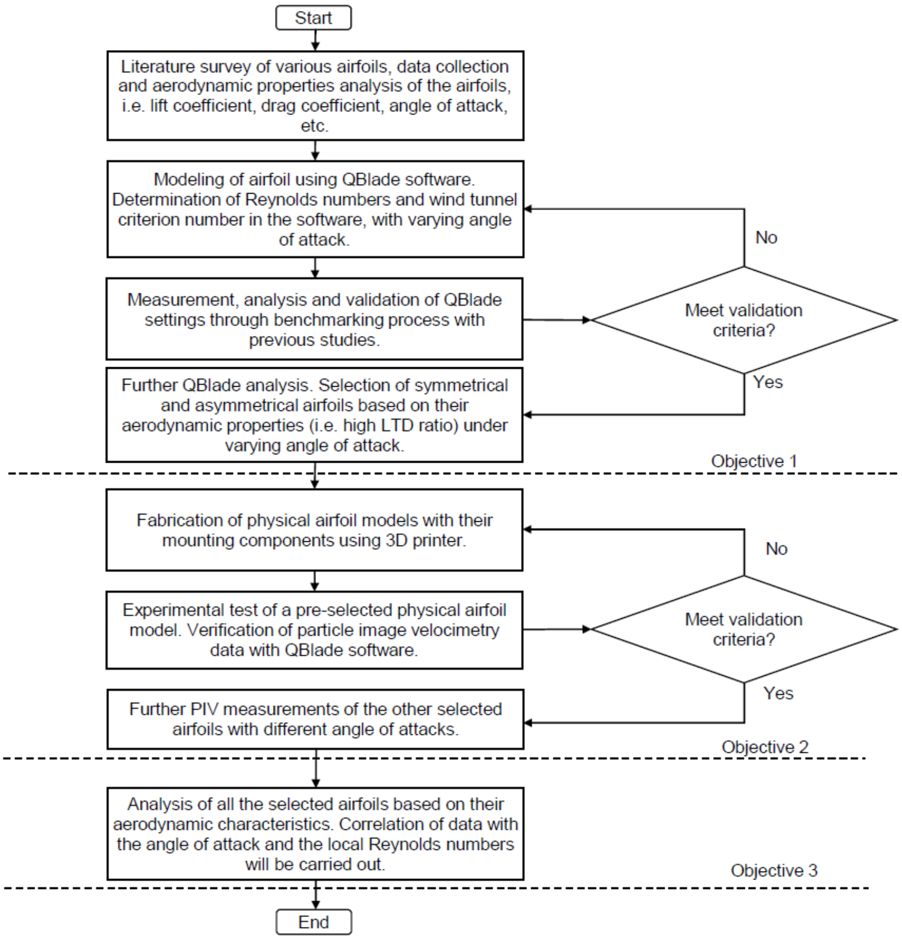

Figure 1.1: Project flowchart

The first stage is a literature evaluation of previous studies on two types of airfoils. This step is essential as all the information regarding the theory of wind turbine, airfoil, selection of airfoils, and the PIV system will take place, where the method and material used will be appropriately selected. The design, as well as the prototype, should be by the reviewed theory from step one. As shown in Figure 1.1, a project flowchart has been designed to assist in this research direction.

1.6 Summary

The efficient use of energy resources and the expanding supply of energy from renewable sources is one of the century's significant concerns. Renewable energy technology must be affordable and perform well to be available to the public. Given this, the design of a wind turbine is not only concerned with the geometrical shape of its rotor; however, the use of an efficient airfoil shape is also essential to developing a high-performance wind turbine, especially in low wind speed regions. The project explores a plethora of airfoil designs based on the NACA 4-series airfoil shape, focusing on airfoil design with high performance (i.e. high LTD ratio) over a wide range of angle of attack. This will ensure that the performance of a wind turbine can be enhanced and available to be used in low wind speed regions.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In the advanced way of life that humanity leads, the energy demand is critical in our day. Traditional methods of electricity generation have taken their toll on the ecosystem, and the planet has been contaminated to unimaginable levels. Alternative energy and green energy derived from natural resources are urgently needed. Technology must be used to meet human needs and give luxury while remaining environmentally friendly. Wind power could be an alternate energy source with a growing knowledge of our needs and goals.

Renewable energy (RE) has undergone significant development during the last two decades, and approaches to electricity generation using renewable technology have been the topic of several studies and research. They are not finite or exhaustible such as wind and solar. These two energy sources are known as an alternative to traditional energy since it is environmentally friendly as it is much less harmful.

Solar energy is produced by capturing sunlight's radiant energy and converting it to heat, electricity, or hot water. Photovoltaic (PV) systems utilise solar cells to convert sunlight into power. By using the turbines, wind farms can capture the energy of wind flow and convert it into electricity. Wind energy is a clean energy source, and it brings a few advantages to using it. It does not emit carbon dioxide or other toxic pollutants that could harm the environment.

2.2 Wind turbine

Figure 2.1: Wind turbine

Source: Inga Spence, n,d

Wind energy has become one of the most critical sustainable energy resources since the energy crisis of the 1970s. Wind turbines as shown in Figure 2.1 are usually used to convert wind kinetic energy into electrical power. According to the alignment of the rotational axis, wind turbines can be categorised into two main types: horizontal-axis wind turbines (HAWTs) and vertical-axis wind turbines (VAWTs). Currently, most commercial wind turbines are deployed as horizontal-axis configurations because HAWTs are more efficient at large scales and have a longer lifetime than VAWT designs (Wang & Zhuang, 2017).There are some differences between a vertical and a horizontal wind turbine. The central rotor shaft of vertical axis wind turbines is fixed vertically, whereas the central rotor shaft of horizontal axis wind turbines is fixed horizontally.

2.2.1 Vertical Axis

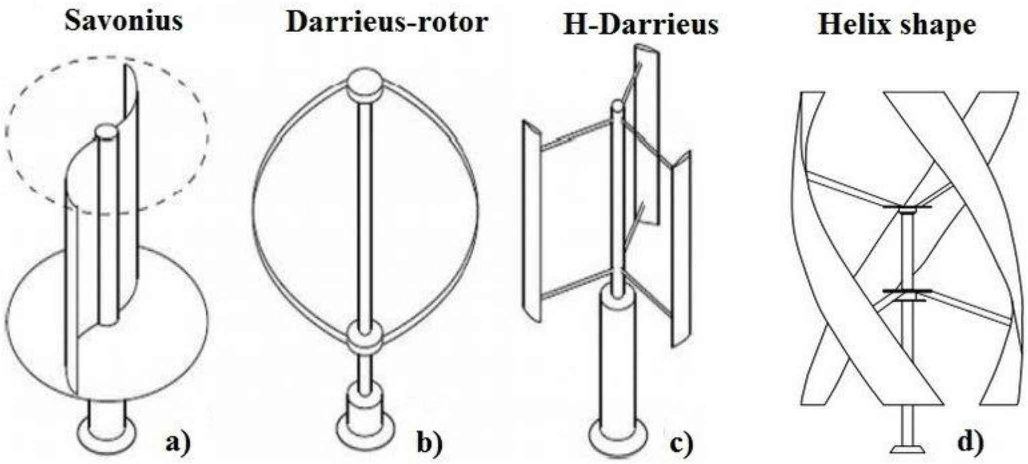

Figure 2.2: Types of vertical axis wind turbine

Source: Castellani et al., 2019

VAWT is a type of wind turbine that was first designed by a Croatian inventor, Fausto Veranzio, in 1595 the main components are found in the base of the turbine, with the main rotor shaft oriented transverse to the wind. This arrangement allows the generator and gearbox to be located close to the ground, facilitating service and repair. VAWTs do not need to be pointed into the wind, which removes the need for wind-sensing and orientation mechanisms (Deshmukh & Charthal, 2017). Vertical axis wind turbines are a unique type of power generation technology. As mentioned, the turbine's rotational axis is vertical or perpendicular to the ground in vertical axis wind turbines. Wind from all directions can power vertical axis turbines, and specific turbines can even be driven when the wind blows from top to bottom. The VAWT was the first wind turbine to be utilised to collect wind energy (Möllerström et al., 2019). However, due to the assumption that VAWT cannot be employed for massive electricity generation, most contemporary academics have lost interest in it.

2.2.2 Horizontal axis

Nowadays, horizontal axis wind turbines are the most common wind turbine designs. Aerodynamic blades are fitted to a rotor positioned upwind or downwind in HAWTs. HAWTs usually have two or three blades and run at high blade tip speeds. There are two major types of horizontal wind turbines: downwind turbines and upwind turbines.

A turbine with the rotor facing the wind is an upwind turbine. This turbine has the advantage of eliminating the wind shadow on the back of the tower. In the downwind turbine, the rotor locates at the tower's downside. The wind faces the tower first, then to the rotor blades.

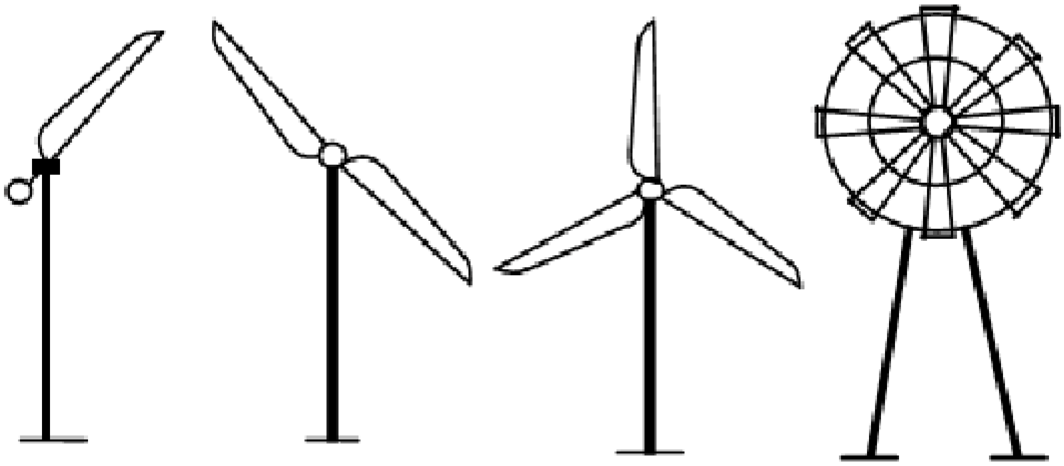

Figure 2.3: Types of horizontal wind turbine

Source: Kalpaktsoglou et al., 2019.

2.3 History of airfoil

An airfoil is the cross-sectional shape of an item that can generate significant lift by moving through a gas, such as a wing, a sail, or the blades of a propeller, rotor, or turbine. In the late 1800s, the first significant work on developing airfoil sections began. Although flat plates were known to produce lift when positioned at an angle of incidence, others believed that shapes with curvature, such as those that resembled bird wings, would produce more lift or do so more effectively. An effective airfoil must have a thin shape, and high curvature is why the first aircraft uses a double wing. The first airfoil shape patent was registered under the name of Horatio F. Phillips in 1884. Phillips was a British national who was the first to conduct airfoils' wind tunnel testing. In 1902 the Wright brothers were testing their airfoil in a wind tunnel to develop an efficient form which later led to their successful first flight on 17 December 1903. The thin and high curvature of the airfoils became increasingly obsolete and gradually dwindled in number over the next decade.(*Airfoil Design*, n.d.)

2.4 What is NACA

The National Advisory Committee for Aeronautics (NACA) was developed an airfoils shape for aircraft wings. The NACA was established on 3 March 1915 by the United States government to conduct, encourage, and institutionalise aeronautical research. The agency was dissolved on 1 October 1958, and its assets and personnel were transferred to the newly established National Aeronautics and Space Administration (NASA) (Jeff Quitney, 2013).

2.4.1 Airfoil development

The first successful airfoil theory, developed by Zhukovsky, was based on an exquisite mathematical concept—the conformal transformation—that exploits the theory of complex variables. Any two-dimensional potential flow can be represented by an analytical function of a complex variable. The basic idea behind Zhukovsky's theory is to make a circle in the complex plane and map it into an airfoil-shaped contour (Houghton, n.d.).

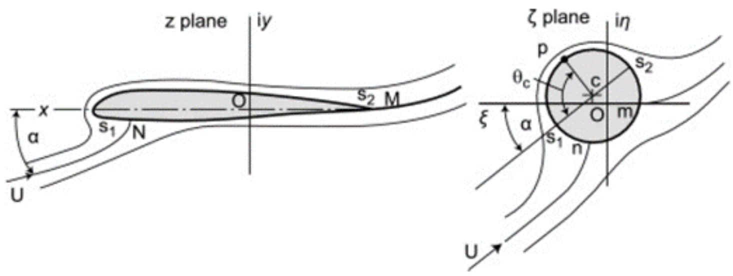

Figure 2.4: Zhukovsky transformation of the flow around a circular cylinder with circulation to the flow around an airfoil generating lift.

Source: Houghton, 2017

In 1998, Kármán and Trefftz devised a more general conformal transformation that made a family of airfoils with trailing edges of finite angle when American engineer Theodorsen established a method for airfoils of any shape in 1931; conformal transformation theory became a practical tool for aerodynamic design. This method was developed well into the second half of the twentieth