AERODYNAMICS DESIGN AND ANALYSIS OF AN RC AIRSHIP USING CFD SIMULATIONS

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DEDICATION

Alhamdulillah

Praise to Allah for the strength, guidance and knowledge that was given by Allah for me to complete this thesis

&

To my beloved parents, families and my friend for their unwavering support and encouragement that was given to me

&

To my supervisor, Ts. Muhammed Noor Bin Hashim for his guidance and advice in completing this thesis

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Thank you to all for always being there, cheering me on, and making this journey more meaningful. This achievement is as much yours as it is mine.

ABSTRACT

This research examines the aerodynamics of a Remote-Control Airship design in order to enhance its maneuverability and efficiency using Computational Fluid Dynamics. Through the analysis of the aerodynamic results of body configurations and propulsion system effects on the stability and control of the airship, a design that optimizes these effects for better performance in indoor observation and monitoring is proposed. An improved-lift and reduced-drag RC airship with enhanced stability and maximum maneuverability are to be designed for surveillance missions, a structure and efficiency analysis, and a working prototype. The methodology will be developed through the selection of appropriate CFD software, geometric modeling, mesh generation, definition of boundary conditions, selection of chambers to define the physical model, simulation execution, post-processing of data, model validation and verification, parametric studies, and setting of challenges and limits. The outcome will be a fair, well-optimized flying prototype of an RC airship with improved aerodynamic performance, ushering in a new and advanced prototype for more comprehensive experiments and investigations.

ABSTRAK

Penyelidikan ini mengkaji prestasi aerodinamik reka bentuk kapal udara kawalan jauh, dengan lebih memfokuskan kepada meningkatkan kemampuan untuk bergerak dan kecekapan melalui ujian eksperimen dan simulasi Dinamik Bendalir Pengkomputeran (CFD). Dengan menganalisis kesan pelbagai konfigurasi sirip dan sistem pendorongan terhadap kestabilan dan kawalan kapal udara ini, kajian ini bertujuan untuk mengoptimumkan reka bentuk aerodinamik bagi meningkatkan prestasi dalam aplikasi seperti pengawasan dan pemantauan dalaman. Objektifnya termasuk mereka bentuk kapal udara kawalan jauh dengan daya angkat yang lebih baik, daya rintangan yang dikurangkan, kestabilan yang dipertingkatkan, dan kemampuan kebolehgerakan yang maksimum, menganalisis struktur dan kecekapan kapal udara tersebut, serta membangunkan prototaip yang berfungsi. Metodologi yang terlibat termasuk pemilihan perisian CFD yang sesuai, pemodelan geometri, penjanaan jejaring, mendefinisikan syarat sempadan, pemilihan model fizikal, pelaksanaan simulasi, pemprosesan data, pengesahan dan pengesahan model, menjalankan kajian parameter, dan menangani cabaran serta keterbatasan. Hasil yang diharapkan adalah prototaip kapal udara kawalan jauh yang dioptimumkan dengan prestasi aerodinamik yang unggul, serta menawarkan pandangan yang berharga untuk reka bentuk dan aplikasi kapal udara masa depan.

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In the Name of Allah, the Most Gracious, the Most Merciful

I want to begin by thanking and praising Allah SWT for granting me the strength and his grace to complete my thesis. Without His love and direction in providing us with strength, patience, and grace, this undertaking would not be feasible.

With my sincerest appreciation, I want to express a million thanks to everyone who assisted me throughout my study. I wish to convey my gratitude to my supervisor, Ts. Muhammed Noor Bin Hashim, for his direction, criticisms, and readiness to lend a hand and advice during this project. From the beginning of the semester until the present, I have admired his generosity, intellect, and expertise.

I'd also want to thank the rest of my family for their prayers, love, inspiration, and encouragement, which motivates me to strive harder to attain my goals and finish this course with success. Finally, I dedicate my thesis to my colleagues who helped me resolve challenges that emerged throughout its completion.

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LIST OF SYMBOLS AND ABBREVIATIONS

RC	-	Remote Control
LiPo	-	Lithium Polymer
CFD	-	Computational Fluid Dynamics
LTA	-	lighter-than-air
WWII	-	World War 2
Fb	-	Buoyant force
ρf	-	Density of the air
V	-	Volume
g	-	Gravity
%	-	Percentage
He	-	Helium
H2	-	Hydrogen
RANS	-	Reynolds-Average Navier-Stokes
LES	-	Large Eddy Simulation
DNS	-	Direct Numerical Simulation
HPC	-	High Performance Computing
PIV	-	Particle Image Velocimetry
CAD	-	Computer-Aided Design
3D	-	3 Dimension
2D	-	2 Dimension
GUI	-	Graphical User Interface
UDFs	-	User-Defined Functions
AMR	-	Adaptive Mesh Refinement
Cp	-	The Pressure Coefficient
Cl	-	Lift Coefficient
Cd	-	Drag Coefficient
Cm	-	Pitching Moment Coefficient
L/D	-	The lift-to-drag ratio

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CHAPTER 1

INTRODUCTION

1.1 Background

A lighter-than-air remote-controlled aircraft known as an RC airship usually generates lift using helium. In addition to being utilised for advertising, leisure activities, and aerial photography, these airships are occasionally employed for surveillance or scientific study. They can be moved in the air thanks to an inbuilt radio transmitter that is controlled by a pilot on the ground.

RC airships find diverse applications ranging from hobby and recreation, where enthusiasts design and fly simple as well as sophisticated models of both contemporary and historical airships, to advertising and promotion, where they are used for displaying information via attached banners or electronic displays, to surveillance and research with onboard cameras and sensors where captured data can be used for aerial photography and research on environmental monitoring. Additionally, they are used as educational tools in the learning of principles of aerodynamics, control systems, and electronics. The design of an RC airship demands a need for an aerodynamics approach to ensure stability and control, most times through the use of Computational Fluid Dynamic simulation for optimum designs. Battery technology, mainly lithium polymer (LiPo) batteries, call for efforts to deliver power to the motors and control systems to enhance flight times and performance. (Liao & Pasternak, 2009).

Aerodynamics Design and Analysis of an RC Airship using CFD Simulations.

The aerodynamics of RC (Remote Control) airships are fascinating, although other systems of control are quite different from those of conventional fixed-wing aircraft or helicopters. It also relies on buoyancy and propulsion for flight, rather lift generated by wings or rotors. There are multiple factors for RC airship including buoyancy, shape and design, control surfaces, stability and control that consists of drag, lift, and propulsion.

1.2 Problem Statement

This research paper has been based on studying the aerodynamic performance of an RC airship design, emphasizing the development of better maneuverability and efficiency for the airship. Using a scaled prototype, the study will mainly deal with experimental testing to see how the factors will affect its stability and control system while using different fin configurations and a variable propulsion system. The results will provide insights into optimizing the aerodynamic design of RC airships for enhanced performance in applications such as indoor surveillance and monitoring.

1.3 Objective

The aerodynamics of the RC Airship will be studied for knowing their design as well as performance, which gets optimized for multiple applications. This means improvement in lift, reduction in drag, stability enhancement, and improvement in maneuverability. Specifically, the main objectives are as follows:

a) To perform CFD simulations on the aerodynamic structure of the RC airship to assess lift, drag, and stability.

b) To evaluate the efficiency of the RC airship's design by simulating airflow patterns.

c) To validate the aerodynamic performance of the RC airship using ANSYS Fluent by comparing simulation results and the benchmarks.

1.4 Scope

The scope of the objective to study the aerodynamics of RC airships includes several key areas:

a) Aerodynamic Principles: Understanding the fundamental principles of aerodynamics as they apply to RC airships, including lift, drag, and stability.

b) Aerodynamic Analysis of the RC Airship: Using CFD simulations in ANSYS Fluent, the project will evaluate the aerodynamic characteristics of the RC airship, including lift and drag coefficients, as well as stability under different flight conditions. This will provide a comprehensive understanding of the airship's aerodynamic behavior and performance.

c) Airflow Pattern Assessment: The airflow patterns around the airship will be simulated to assess the efficiency of its design. This includes analyzing flow separations, wake regions, and pressure distributions to identify potential improvements in the airship's geometry for enhanced aerodynamic performance and energy efficiency.

d) Control Systems: Investigating the impact of different control systems on aerodynamic stability and maneuverability.

e) Validation of Simulation Results: The simulation results will be validated by comparing them with benchmarks such as experimental data, analytical models, or results from existing literature. This ensures the reliability and accuracy of the CFD predictions, establishing confidence in the methodology used.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The aerodynamics involved in RC (Remote Control) airships can be very interesting and, at the same time, somewhat different from the conventional fixed-wing aircraft or helicopter. RC aerostats are in large part dependent on buoyancy and propulsion, whilst fixed-wing aircraft basically rely on lift created by wings, and helicopters rely on lift created by their rotors. Several considerations are taken into account in an RC airship, including buoyancy, shape and design, control surfaces, stability and control, and propulsion.

Digital modeling and simulation of the aerodynamics of an RC (Remote Control) airship using CFD (Computational Fluid Dynamics) are a sophisticated way of handling the optimization of performance and efficiency of these lighter-than-air vehicles. It would involve creating detailed digital models of the airship and simulating its behavior in a virtual wind tunnel to understand how air would flow around the structure. (Amol C. Gawale, 2008)

For instance, CFD simulation can be used to consider the lift, drag, stability, and control effectiveness when during flight situations, which are usually considered in detail for varied flight conditions. This approach can specifically tune the airship shape, fin composition, and propulsion system in such a way to result in minimal aerodynamic drag and maximum flexibility (Paluszek, 2004). Other aspects that can be obtained by means of CFD simulations include the performance of the airship in various environmental conditions, therefore ensuring both reliability and efficiency.

Using iterative design and analysis, CFD can give substantial insight for the determination of more efficient and effective RC airship design, thus enabling advanced envisaged application in surveillance advertising and environmental monitoring. This high-tech approach to aerodynamics helps in obtaining optimal performance while simultaneously reducing the time and cost associated with traditional experimental testing (Pant, 2014).

2.2 Airship history

An airship, also known as a dirigible, is a lighter-than-air (LTA) aircraft that can be steered and propelled using engines. Unlike balloons, which are free-floating, airships can navigate and maneuver under their own power, achieving lift through gases like helium or historically, hydrogen. There are three main types of airships: rigid airships with a structural framework (such as the famous Zeppelins), semi-rigid airships with a partial structure, and non-rigid airships or blimps that maintain shape through internal gas pressure. The primary components of an airship include the envelope, which holds the lifting gas, the gondola or control car for the crew and controls, the propulsion system with engines and propellers, and control surfaces like fins and rudders for navigation (Dick, 1992).

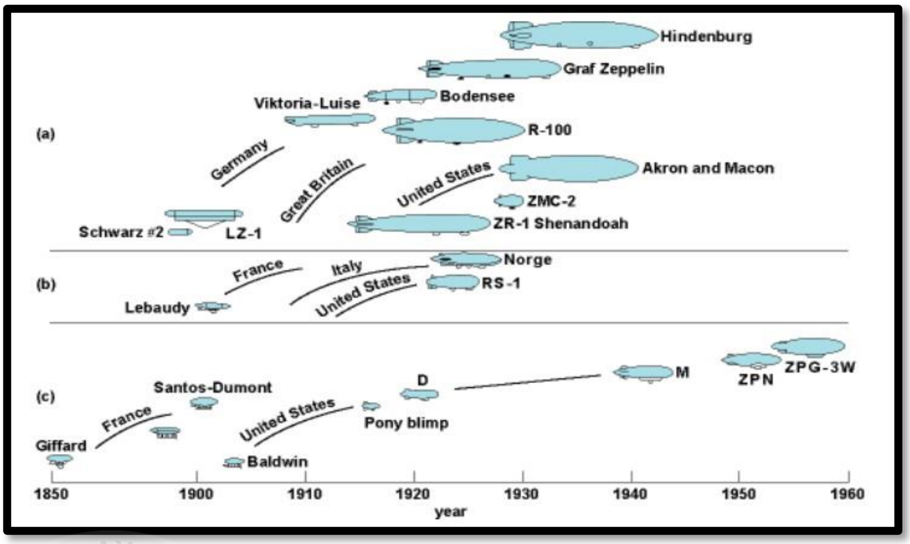

Figure 2.1 History of Airship Development. (a) Rigid Airships. (b) Semi-rigid Airships. (c) Non-rigid Airships. *(Stockbridge C, 2012)*

Airships have a rich history (Althoff, 2004),beginning in the late 19th century with the first practical models, like Henri Giffard's steam-powered airship in 1852. The early 20th century saw the prominence of rigid airships for passenger transport and military use, exemplified by Zeppelins. However, the Hindenburg disaster in 1937 marked a significant setback. Post-WWII advancements renewed interest in airships for military, advertising, and research applications. Today, airships are used for various purposes, including aerial advertising, surveillance, tourism, cargo transport, and environmental monitoring. They offer advantages such as low environmental impact, vertical takeoff and landing capabilities, and stability for prolonged hovering. However, challenges remain, including vulnerability to weather conditions and helium supply issues. Future developments in airship technology promise improved materials, hybrid propulsion systems, and advanced navigation, enhancing their capabilities and reliability for diverse applications (Dewar, 2002).

2.3 RC Airship

An RC (radio-controlled) airship is a type of a LTA [lighter than air] aircraft, which is remotely controlled by an operator via a radio control system. This type of airship floats in air using the principle of buoyancy mixed with aerodynamics, most often of helium gas. An RC airship is smaller than a conventional kind and finds a lot of applications, such as recreational aerostation, advertising, surveillance, and purely educational (De Vries, 2013). Compact includes an envelope, which contains gas; a gondola, which contains the propulsion system and electronics for controlling the airship; and control planes, a rudder, and elevators used for maneuvering. Development and acceptance of RC airships are expected to expand due to the attractiveness of their unparalleled stability, low environmental impact, and further unique flying properties that lend their uses to a wide variety of innovative uses. Lightweight materials, advanced propulsion technology, and electronic control will further extend possible applications in the sky (Johnson, 2010).

2.4 Aerodynamics of Airships

Aerodynamics of airships focuses on how these lighter-than-air vehicles interact with the atmosphere to achieve and maintain flight. Unlike airplanes that rely on aerodynamic lift generated by wings, airships primarily depend on buoyant lift provided by gases such as helium or hydrogen. However, aerodynamic principles still play a crucial role in their design and operation. The key concepts are buoyancy and lift, design and shape, forces acting on an airship, stability and control and Computational Fluid Dynamics (CFD). (Khoury G. A., 1998)

2.4.1 Buoyancy and Lift

The aerodynamics of airships fundamentally relies on buoyancy, like how boats float on water, based on Archimedes' principle. Airships are filled with lighter-than-air gases like helium or hydrogen, creating an upward buoyant force due to the density difference with the surrounding air (Lin Liao, 2009). Helium is often preferred for its non-flammable nature, while hydrogen, despite its greater lift, poses significant flammability risks. This buoyant force acts on the airship's large envelope, designed to displace enough air to lift the airship and its payload.

Achieving neutral buoyancy, where the upward buoyant force equals the downward gravitational force, allows the airship to remain suspended in the air. Aerostatic lift, provided by buoyant gas, is the primary source of lift and is a static force. In addition, the airship's streamlined shape can generate minor aerodynamic lift as it moves through the air, like an airplane wing. The angle of attack and the design of control surfaces like horizontal stabilizers and fins can control this aerodynamic lift.

Airships make use of ballast systems to manage buoyancy and ensure that the altitude remains constant; to this, the volume of lifting gas is changed. Ballast, either water or sand is released to reinforce buoyancy, while the amount of gas, which can be compressed or released, for helium could be elements to fine-tune the buoyancy. This careful balance between buoyancy and lift results in ascending, descending, or soaring. They facilitate energy-carrying and welcome a big mess of payloads, since airships are able to do hovering yet undertake the transfer of bulky loads from one place to another, making them useful for various applications ranging from surveillance and show advertising to cargo carriage to places that are hard to reach. The knowledge and skills required to make these principles work are fundamental for the effective operation and versatility of airships (Allen, Airship Design and Engineering, 2012).

2.4.1.1 Archimedes Principle

Buoyancy is a critical element in the design and operation of airships and, therefore, needs to be understood clearly, and handling of Archimedes' Principle forms the basic explanation. Archimedes' Principle explains that an object submerged in any form of fluid is presented with an upward force, that is buoyant force, which happens to be equal to the weight of the fluid that had been displaced via that object.

Archimedes' Principle Explained

Archimedes' Principle can be mathematically expressed as:

$$F_b = \rho_f \cdot V \cdot g$$

Where:

- Fb is the buoyant force.
- ρf is the density of the fluid (in the case of airships, the density of the air).
- V is the volume of the fluid displaced by the object.
- g is the acceleration due to gravity.

For an airship, the principle implies that the buoyant force is equal to the weight of the air displaced by the helium or hydrogen gas inside the envelope. This buoyant force must be sufficient to lift the weight of the airship, including its envelope, gondola, passengers, cargo, and propulsion system.

Referring to the Table 2.1 below, shows Archimedes' Principle to Airships

Table 2.1 Archimedes' Aspect

Aspect	**Description**
Lift Generation	The airship's envelope is filled with a gas like helium that is less dense than the surrounding air. This density difference creates a buoyant force that lifts the airship. The lift generated must balance the total weight of the airship for it to float.
Volume and Density	The larger the volume of the envelope, the greater the buoyant amount force, since more air is displaced. The choice of gas also affects the buoyancy of helium as a gas is lower than hydrogen. Therefore, preferred for its non-flammability.
Weight Considerations	The total weight of the airship includes the envelope material, gondola, cargo, fuel, and any additional equipment. Engineers must ensure that the buoyant force exceeds this total weight for the airship to ascend. The total weight of the airship includes the envelope material, gondola, cargo, fuel, and any additional equipment. Engineers must ensure that the buoyant force exceeds this total weight for the airship to ascend.
Ballast and Trimming	Airships use ballast (weight that can be added or removed) to adjust buoyancy. Ballast adjustments are critical for maintaining altitude and stability, especially when loading or unloading cargo or passengers.

2.4.1.2 Lighter-than-Air Gases

The choice of gas used in airships is crucial due to its direct impact on buoyancy, safety, and operational efficiency. The two primary gases historically used in airships are helium and hydrogen (Fulton, 2009). Figure 2.2 shows the periodic table of the elements.

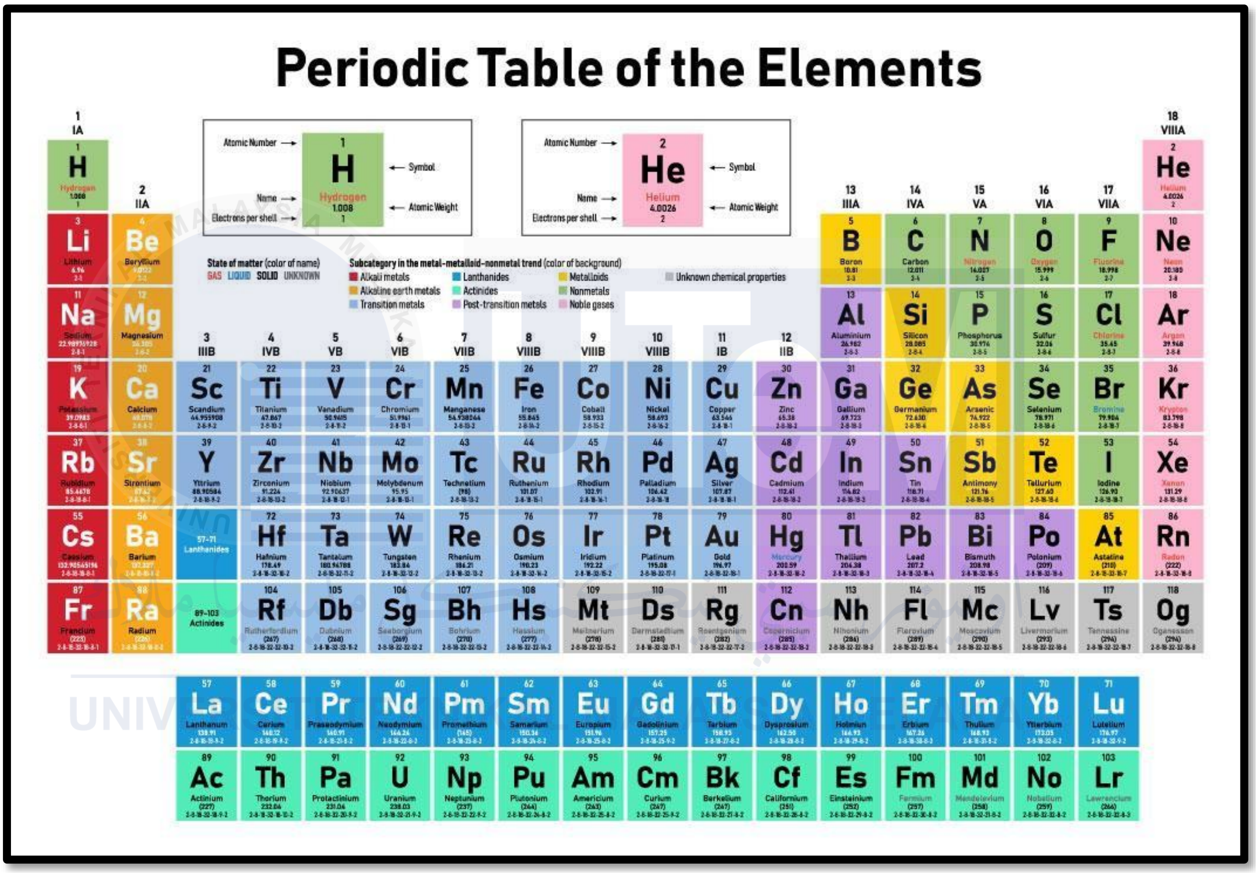

Figure 2.2 Periodic Table of the Elements (Focusing on Helium & Hydrogen)

Helium

Helium is a noble gas with the chemical symbol He. It is the second lightest and second most abundant element in the observable universe. Helium's key properties for use in airships shown in Table 2.2.

Table 2.2 Property of Helium

Property	**Description**
Non-Flammable	Helium is non-flammable, making it much safer than hydrogen. This property is particularly important for airships operating in populated areas or carrying passengers and valuable cargo.
Buoyancy	Helium provides about 92% of the lift of hydrogen. While not as buoyant as hydrogen, its safety advantages often outweigh the slight reduction in lift.
Inertness	Helium is chemically inert, meaning it does not react with other substances. This inertness ensures that helium does not degrade materials or equipment in contact with it.

Hydrogen

Hydrogen, with the chemical symbol H2, is the lightest element and provides the greatest buoyancy. Its properties include in Table 2.3 below.

Table 2.3 Property of Hydrogen

Property	**Description**
High Buoyancy	Hydrogen offers approximately 10% more lift than helium. This higher lift can be advantageous for carrying heavier loads or achieving greater altitude.
Flammability	The major drawback of hydrogen is its flammability. Hydrogen gas can form explosive mixtures with air, leading to several historical airship disasters, most notably the Hindenburg disaster in 1937.

Property	Description
Abundance and Cost	Hydrogen is more abundant and cheaper to produce than helium, which can be a significant factor in large-scale or budget-constrained operations.

Historical and Modern Use

Historically, hydrogen was widely used in airships due to its superior lifting capability and low cost. However, the safety risks associated with hydrogen led to a shift towards helium, particularly after the Hindenburg disaster. Today, helium is the preferred lifting gas for most airships due to its safety profile (Anderson R. D., 1998).

Practical Considerations

i. **Gas Containment:** Both gases require well-sealed, durable envelopes to prevent leakage and maintain the lift. Modern materials such as advanced fabrics and composites are used to construct these envelopes.

ii. **Operational Safety:** For helium-filled airships, the primary concern is maintaining the purity and pressure of the gas. For hydrogen, stringent safety protocols are necessary to prevent ignition and ensure safe handling (Smith J. &., 2015).

2.4.1.3 Aerostatic and Aerodynamic Lift

Airships rely on both aerostatic and aerodynamic principles to achieve and maintain flight (Allen, Airship Design and Engineering, 2012). Understanding these concepts is crucial for the design and operation of airships.

Aerostatic Lift

Aerostatic lift is the buoyant force that allows an airship to float in the air. This lift is governed by Archimedes' Principle, which states that any object submerged in a fluid (in this case, air) experiences an upward force equal to the weight of the fluid displaced by the object. For airships, the fluid is the surrounding air, and the displaced volume is determined by the envelope filled with a lighter-than-air gas such as helium or hydrogen (Smith R. M., 2008).

Aerodynamic Lift

While aerostatic lift is the primary lifting mechanism for airships, aerodynamic lift also plays a role, especially when the airship is in motion. Aerodynamic lift is generated by the flow of air over the airship's hull and control surfaces (Anderson J. D., 2010).

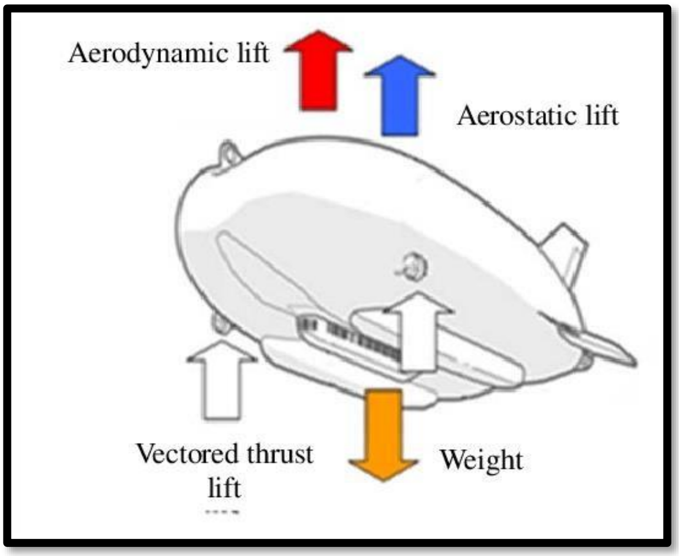

Figure 2.3 Direction of Aerodynamic lift & Aerostatic lift *(Prentice, 2014)*

Table 2.4 shows few aspects of Aerostatic & Aerodynamic lift including its description

Table 2.4 Differentiation between Aerostatic lift & Aerodynamic lift

Aspect	**Aerostatic Lift**	**Aerodynamic Lift**
Principle	Buoyancy (Archimedes principle)	Airflow over surfaces (Bernoulli's principle and Newton's third law)
Mechanism	Displacement of air by lighter-than-air gas (e.g., helium, hydrogen)	Pressure differences over the hull and control surfaces
Dependency on Movement	Not dependent on movement	Dependent on movement through the air
Lift Control	Adjusting volume of lifting gas or ballast	Adjusting speed, shape, and angle of attack
Stability	Provides constant lift; less maneuverable	Provides variable lift; more maneuverable
Primary Use	Main lift mechanism for maintaining altitude	Supplementary lift for enhanced control and stability
Effectiveness	Effective always, including when stationary	Effective only when the airship is moving
Design Considerations	Requires large volume of gas	Requires aerodynamic shaping and control surfaces
Applications	Essential for basic flight capability	Enhances performance during takeoff, landing, and maneuvering
Energy Efficiency	Generally, energy-efficient due to passive nature	Requires energy to maintain motion for lift generation

Aspect	Aerostatic Lift	Aerodynamic Lift
Impact of Weather	Less affected by wind and turbulence	Can be significantly affected by wind and turbulence
Historical Usage	Traditional airships (e.g., Zeppelins, blimps)	Modern hybrid airships and advanced designs

Integration of Aerostatic and Aerodynamic Lift

According to Leland, D. K. (Leland, 2015),for effective operation, airship designs integrate both aerostatic and aerodynamic principles:

iii. **Balance and Stability**: The combined effects of aerostatic buoyancy and aerodynamic forces must be balanced to maintain stable flight.

iv. **Control**: Control surfaces and propulsion systems are designed to harness aerodynamic lift for better maneuverability and stability, especially in varying wind conditions.

v. **Efficiency**: Optimizing the shape of the airship and the distribution of lift forces reduces drag and improves fuel efficiency.

2.4.1.4 Ballast Systems and Gas management in Airships

Effective management of buoyancy and ballast is a critical component for the safe and efficient operation of airships. These systems ensure that the airship can maintain, adjust, and control its altitude and stability during flight.

Ballast Systems

Ballast systems in airships are used to control the airship's weight and adjust its buoyancy. By adding or removing ballast, the airship can maintain neutral buoyancy, ascend, or descend as needed (Smith J. , 2020). The primary components of ballast systems include:

vi. **Water Ballast:** Water is the most used ballast due to its availability and ease of use. Tanks located in the gondola or along the hull hold water, which can be released to reduce weight and increase buoyancy.

vii. **Solid Ballast:** In some cases, solid materials such as sandbags are used as ballast. These can be manually added or removed to adjust the airship's weight.

viii. **Automatic Ballast Systems:** Modern airships often use automated systems to manage ballast. These systems can release water ballast in response to changes in altitude or payload, maintaining stable flight conditions.

ix. **Trim Ballast:** To adjust for uneven weight distribution and maintain proper trim (balance), smaller ballast adjustments are made. This is essential for ensuring the airship remains level and controllable (Doe, 2021).

Gas Management

Gas management involves maintaining and controlling the volume and pressure of the lifting gas (helium or hydrogen) within the airship's envelope (Jones, 2019). Key aspects include:

i. **Gas Cells:** The envelope of an airship typically contains multiple gas cells or compartments. This design helps manage the distribution of the lifting gas and enhances safety by reducing the risk of a single leak compromising the entire airship.

ii. **Pressure Control:** Maintaining the correct pressure within the gas cells is crucial. Too much pressure can strain the envelope, while too little can result in a loss of lift. Valves or regulators are used to control the pressure of the gas.

iii. **Helium Purity:** For helium-filled airships, maintaining gas purity is important to ensure consistent buoyancy. Contaminants or leaks can reduce the effectiveness of the lifting gas (Brown R. &., 2020).

iv. **Gas Venting:** During ascent, the lifting gas expands due to lower atmospheric pressure. Excess gas is vented to prevent over-pressurization. Conversely, during descent, the gas contracts, and compensating for this volume change is necessary to maintain lift.

v. **Ballonets:** These are internal air-filled bags within the envelope. By inflating or deflating ballonets, the airship can adjust the internal pressure and volume of the lifting gas, aiding in altitude control.

Practical Management Techniques

i. **Altitude Adjustment:** To ascend, the airship releases ballast or increases the volume of lifting gas. To descend, ballast is added, or gas is vented, and ballonets are inflated to reduce the lifting gas volume (Henderson, 2021).

ii. **Load Compensation:** When picking up or dropping off cargo or passengers, ballast adjustments ensure the airship remains balanced and buoyant.

iii. **Weather Considerations:** Wind, temperature, and atmospheric pressure changes impact buoyancy. Active gas and ballast management are required to adapt to these conditions during flight (Taylor, Operational Techniques for Modern Airships, 2022).

2.4.1.5 Application and Efficiency in Airships

Airships, with their unique capabilities, have found renewed interest for various modern applications. Their efficiency in certain roles, combined with advancements in technology, makes them viable alternatives or complements to traditional aircraft and other modes of transportation (Brown R. &., 2019).

Applications of Airships

i. Surveillance and Reconnaissance:

a) Military and Security: Airships can provide persistent aerial surveillance and reconnaissance due to their ability to loiter at high altitudes for extended periods. Equipped with advanced sensors and cameras, they offer a stable platform for monitoring large areas.

b) Environmental Monitoring: Airships can be used to monitor environmental conditions, including air quality, wildlife habitats, and forest health. Their ability to hover and move slowly makes them ideal for detailed observations.

ii. Cargo Transport:

a) Heavy and Oversized Loads: Airships can transport heavy and oversized cargo that might be difficult or impossible to move by road or traditional aircraft. Their vertical takeoff and landing capabilities allow them to operate in areas without extensive infrastructure.

b) Remote Area Supply: Inaccessible regions, such as arctic areas, jungles, or islands, can benefit from airship logistics, providing essential supplies where traditional transport methods are impractical.

iii. Tourism and Advertising:

a) Scenic Flights: Airships offer unique and scenic travel experiences, providing passengers with panoramic views from a comfortable and stable platform.

b) Aerial Advertising: Airships can serve as moving billboards, displaying advertisements for overpopulated areas or events, attracting significant attention. (Taylor, Efficiency and Applications of Modern Airships, 2021)

iv. Disaster Relief and Humanitarian Aid:

a) Emergency Response: In the aftermath of natural disasters, airships can deliver critical supplies and medical aid to affected areas. Their ability to hover and access areas with damaged infrastructure is particularly valuable (Khoury G. , 2012).

b) Search and Rescue: Airships can assist in search and rescue operations, providing aerial support and transporting rescue teams and equipment.

v. Scientific Research:

a) Atmospheric Studies: Airships can serve as platforms for atmospheric research, collecting data on weather patterns, pollution, and climate change.

b) Oceanographic and Geological Surveys: They can be equipped with specialized instruments to conduct surveys over oceans and remote land areas, collecting data for scientific research (Cook, 2004).

Efficiency Aspects of Airships

i. Fuel Efficiency:

Low Fuel Consumption: Airships carry light loads, which is way lighter compared to conventional aircraft; have markedly lower fuel consumption because of the much greater degree of static lift from buoyancy.

i. **Operational Flexibility:**

Versatility: Airships, without being dependent on cumbersome and expensive ground-based infrastructure, can manage in a variety of environments including those which are remote and rugged. This flexibility reduces operational costs and increases their utility in diverse applications.

ii. **Long Endurance:**

Extended Flight Duration: Airships can remain airborne for days or even weeks, making them ideal for missions requiring prolonged presence, such as surveillance, environmental monitoring, and research.

iii. **Minimal Infrastructure Requirements:**

Simplified Logistics: Airships fly without the needs of runways and with a minuscule need for airports, so, as such, they can operate from simple mooring stations. Very little expensive infrastructure is needed in this case, making them particularly well suited to remote or underdeveloped regions.

2.4.2 Design and Shape of Airships

The design and shape of airships are critical for their aerodynamic efficiency, stability, and overall performance. The streamlined form of an airship minimizes drag, which is essential for efficient flight.

Streamlined Shape:

a) Cigar Shape: The typical airship has a cigar-shaped hull. This streamlined form reduces drag by allowing air to flow smoothly around the structure. The elongated shape ensures that the frontal area (which faces the oncoming air) is minimized, thus reducing form drag as shown in Figure 2.4.

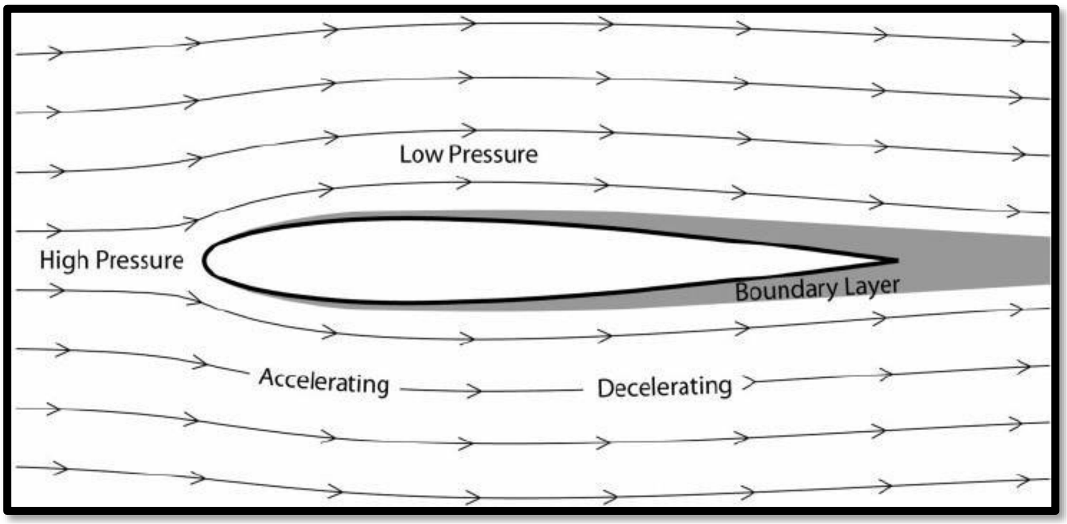

Figure 2.4 Streamlined form *(McHenry, 2009)*

b) Elliptical Cross-Section: Some airships utilize an elliptical cross-section to further reduce drag and enhance stability. This design helps in reducing turbulence and vortex formation at the rear of the airship, which can contribute to drag. The Figure 2.5 below shows the Elliptical Cross-Section.

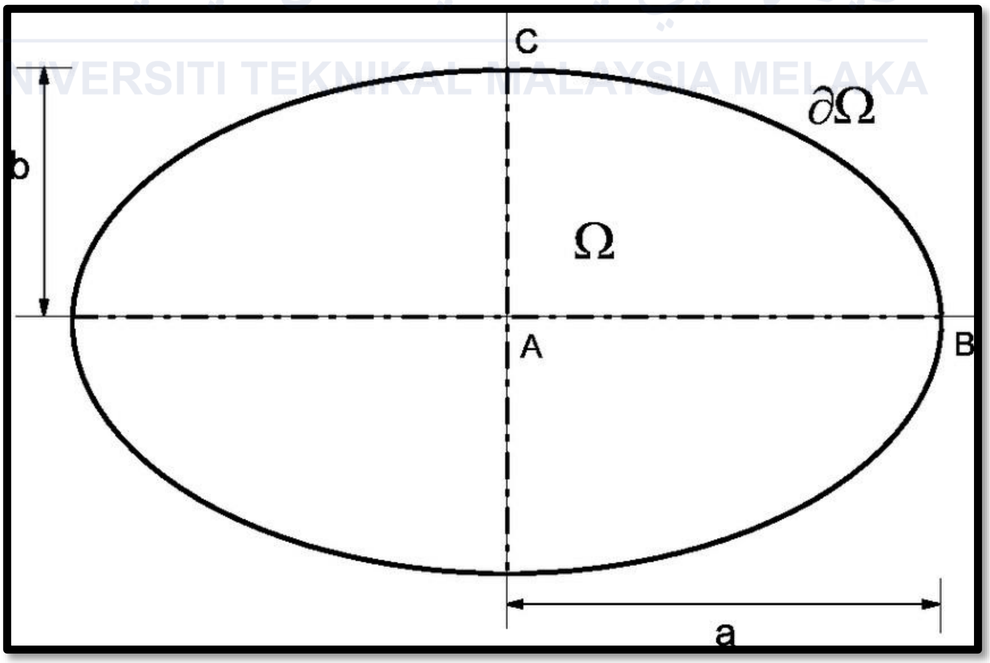

Figure 2.5 The Elliptical Cross-Section *(Jankowska, 2019)*

Control Surfaces:

a) Fins and Rudders: Airships are equipped with fins and rudders, usually located at the tail. These control surfaces are crucial for steering and stability. The vertical fins and rudders control yaw (side-to-side movement), while horizontal fins control pitch (up-and-down movement).

b) Empennage: It's a tail structure consisting of fins and rudders that maintain directional stability and control. The design of these surfaces affects the way the airship is manageable and maintains a stable course.

Structural Design:

a) Envelope Material: Usually, the outer skin or envelope of the airship is made of lightweight, strong, durable material like polyester fabrics coated with polyurethane or other advanced polymers. This material has to be strong to constrain the lifting gas to deal with the environmental factors.

b) Internal Framework: In some designs, there are lightweight metallic internal frameworks like aluminum or carbon fiber, which are installed for reasons concerning stability and shape. In the more modern airships, however, there are semi-rigid or non-rigid platforms upon which the hull is placed. The hull, therefore, obtains its shape mainly as a pressurized envelope and is not evidently dependent on a rigid frame.

The figure 2.6 shows the anatomy of an airship in the form of a classic blimp.

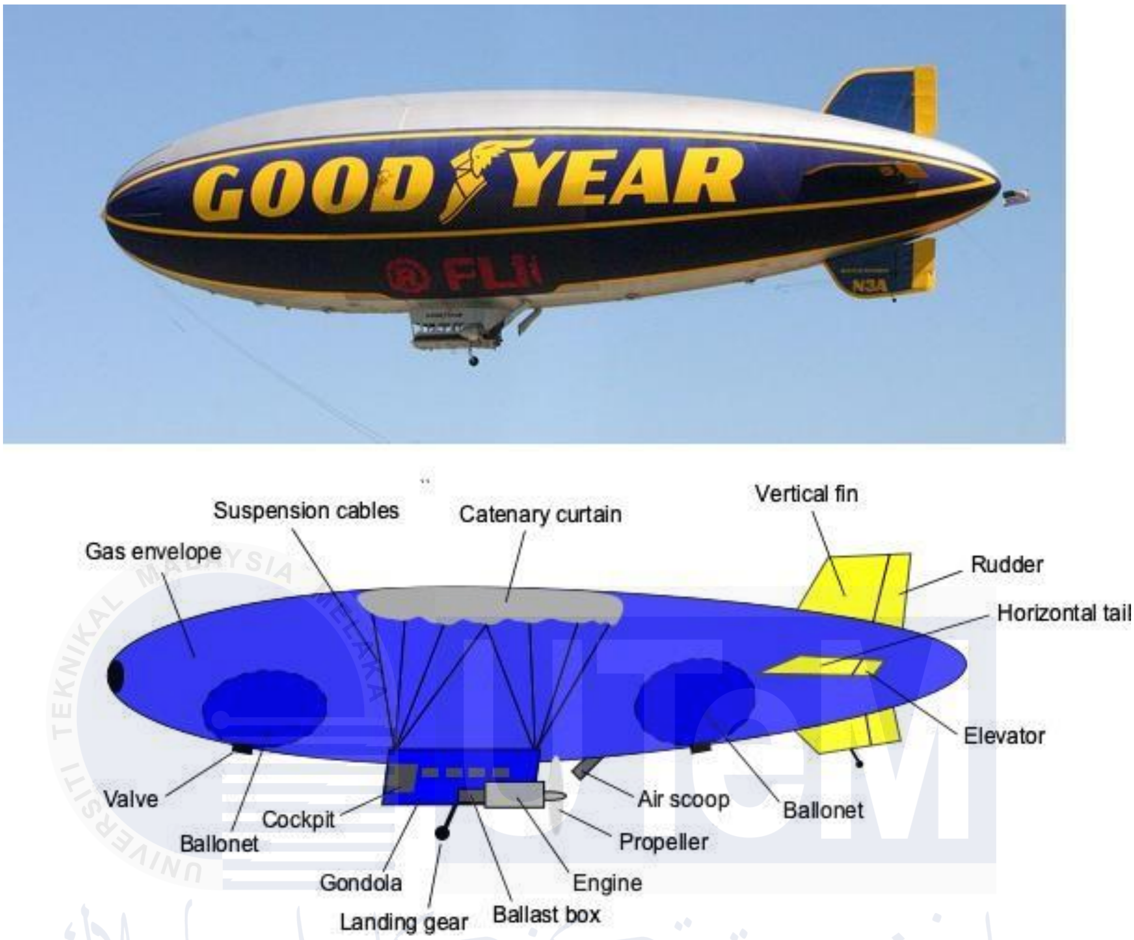

Figure 2.6 Anatomy of an airship in the form of a classic blimp *(Goodyear, 2022)*

Balancing and Stability:

a) Weight Distribution: Proper weight distribution is important for the stability of an airship. All this is achieved through how different mass payloads, fuel, and ballast are placed to offer it the capability to balance and avoid tilting and rotation.

b) Ballast System: Adjustable ballast systems allow the airship to fine-tune its buoyancy and balance. In a certain designs, the inclusion of water or sand ballast can be added or released to adjust trim requirements.

Aerodynamic Considerations:

a) Drag Reduction: Drag is minimalized during the design. Form drag, skin friction, and interference drag are minimized by smooth surfaces and streamlined shapes, reducing the parasitic drag. The ultimate goal is to create a shape that allows air to flow by it with as little resistance as possible.

b) Flow Separation: Designers try to prevent flow separation. This happens when free stream airflow separates from the surface, forming turbulent air, which causes drag. The hull and control surfaces should, therefore, be quite careful to be of much help.

Propulsion and Thrust:

a) Engine Placement: Engines or propellers are generally mounted at the sides or the rear of the airship. Their placement is such that they give the required thrust while maintaining aerodynamic efficiency and stability.

b) Thrust Vectoring: Some modern airships use thrust vectoring, literally vectors of propulsive thrust, where the direction of the thrust can be altered to provide assistance in maneuvering and stabilizing.

In summary, the design and shape of an airship are very important for drag reduction, better stability, and flying efficiency. The streamlined, often cigar-shaped hull, strategically placed control surfaces, and a well-balanced structure all contribute to the aerodynamic performance of the ship. The use of advanced materials and engineering ensures the shape and structural integrity of the ship while optimizing it for various applications.

2.4.3 Forces Acting on an Airship

Airships, like all aircraft, are subject to several forces that affect their motion and behavior in flight. Understanding these forces is essential for designing and operating airships safely and efficiently.

i. Lift

Lift is the upward force that counteracts the weight of the airship, allowing it to overcome gravity and stay aloft. Lift is generated primarily by the difference in air pressure above and below the airship's envelope. Factors influencing lift include the shape and size of the envelope, the density of the lifting gas, and the speed of the airship through the air.

ii. Weight

Weight is the force of gravity acting on the airship. It is the total mass of the airship, including its envelope, payload, fuel, and any passengers or cargo. The weight of the airship must be balanced by the lift generated to maintain level flight.

iii. Drag

Drag is the resistance the airship encounters as it moves through the air. It is caused by friction between the air and the airship's surface, as well as by the disruption of airflow around the airship's shape. Drag reduces the airship's speed and efficiency, so minimizing drag is crucial for improving performance.

iv. Thrust

Thrust is the forward force that propels the airship through the air. It is usually generated by engines or propellers attached to the airship's gondola or hull. Thrust must be greater than drag for the airship to accelerate and maintain forward motion.

v. **Stability and Control**

In addition to these primary forces, airships also rely on stability and control forces to maintain their orientation and direction of flight. These forces are generated by control surfaces such as rudders, elevators, and ailerons, which are used to steer the airship and maintain stability in various flight conditions. Forces acting on Airship shown in the Figure 2.7 below.

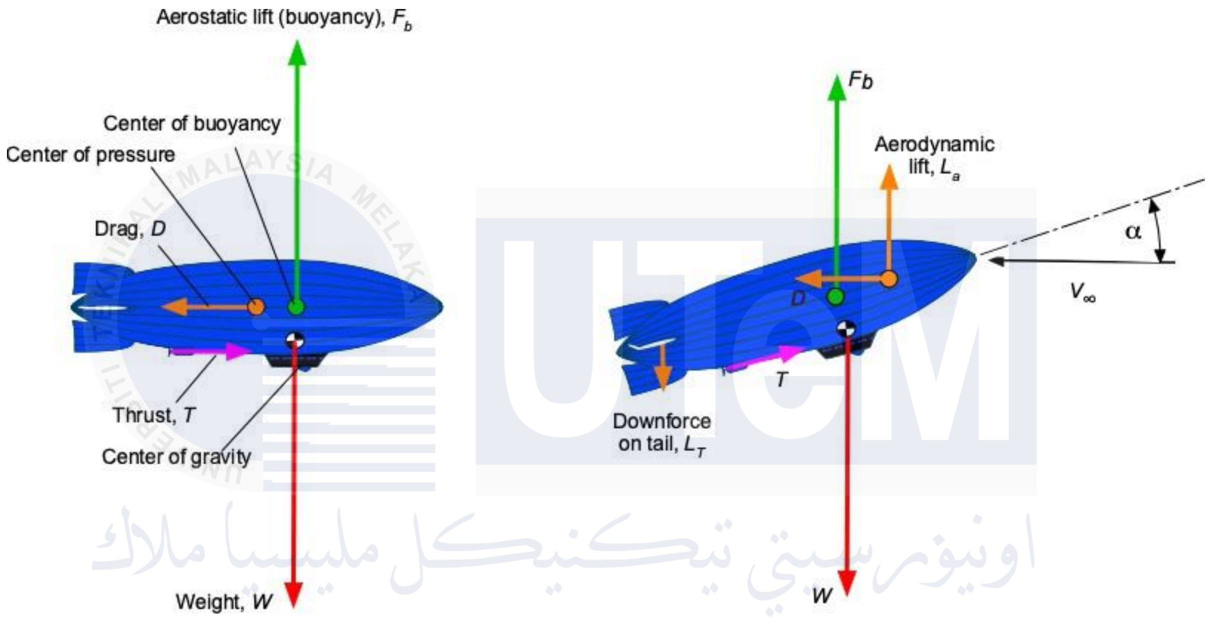

Figure 2.7 Forces acting on Airship *(eaglepubs, 2022)*

2.4.4 Stability and Control of Airships

Stability and control are critical aspects of airship design and operation, ensuring safe and efficient flight. These concepts govern the airship's ability to maintain a steady course, respond to pilot inputs, and remain stable in various flight conditions.

Stability

i. **Static Stability:** Static stability refers to the airship's ability to return to its original position after being disturbed. There are three types of static stability:

a) **Positive Stability:** The airship returns to its original position after a disturbance, indicating a stable configuration.

b) **Neutral Stability:** The airship remains in its new position after a disturbance, indicating a neutrally stable configuration.

c) **Negative Stability:** The airship continues to move away from its original position after a disturbance, indicating an unstable configuration.

ii. **Dynamic Stability:** Dynamic stability refers to the airship's ability to maintain a steady flight path over time. It involves damping out oscillations and disturbances, ensuring smooth and controlled flight.

Control

i. **Control Surfaces:** Airships use control surfaces such as rudders, elevators, and ailerons to control their orientation and direction. These surfaces are manipulated by the pilot to steer the airship and maintain stability.

ii. **Ballonets:** Ballonets are air-filled bags within the envelope that can be inflated or deflated to control the airship's overall density. By adjusting the pressure in the ballonets, the airship can compensate for changes in weight and buoyancy, aiding in altitude control and stability.

iii. **Propulsion Systems:** Thrust from engines or propellers is used to control the airship's speed and direction. By varying the thrust, the pilot can make adjustments to the airship's course and maintain stability.

Factors Influencing Stability and Control

i. **Envelope Design:** The shape and size of the envelope play a crucial role in the airship's stability. A streamlined envelope reduces drag and improves stability.

ii. **Weight Distribution:** Proper weight distribution is essential for stability. Uneven weight distribution can lead to instability and difficulty in controlling the airship.

iii. **Wind Conditions:** Airships are sensitive to wind conditions. Crosswinds and gusts can affect stability, requiring adjustments from the pilot.

2.4.5 Computational Fluid Dynamics (CFD) in Airship Design

Computational fluid dynamics in designing and analysing airships is a very powerful tool that gives the engineer detailed airflow, airship aerodynamics information on all types of airships. CFD can simulate the aerodynamic forces and moments and provide data to optimize the design to achieve and improve the efficiency or stability or maneuverability of the airship.

Working Principle of CFD

i. **Numerical Simulation:** CFD involves discretizing the fluid domain around the airship into a grid of small computational cells. The governing equations of fluid flow, such as the Navier-Stokes equations, are then solved numerically for each cell to simulate the airflow.

ii. **Boundary Conditions:** Boundary conditions are applied to the computational domain to model the airflow around the airship. These conditions include the airspeed, pressure, and temperature at the airship's surface.

iii. **Solution Process:** The CFD software iteratively solves the discretized equations to calculate the airflow velocities, pressures, and other flow properties throughout the domain. This process provides a detailed understanding of the airflow behavior.

iv. **Analysis and Optimization:** By CFD results, Engineers can get information about the areas of high drag, turbulence, or separation of flow around the airship. On the basis of this information, engineers can make the necessary changes in the design of the airship for its better aerodynamic performance. Airships are quite difficult to handle aerodynamically.

Applications of CFD in Airship Design

i. **Shape Optimization:** CFD simulations can be used to evaluate different airship shapes and configurations to minimize drag and improve aerodynamic efficiency. Engineers can explore various design options to achieve the desired performance characteristics.

ii. **Stability and Control Analysis:** CFD helps in analyzing the stability and control of airships by predicting the aerodynamic forces and moments acting on the airship. This information is crucial for designing effective control systems and ensuring stable flight.

iii. **Performance Prediction:** CFD can predict the lift, drag, and other aerodynamic forces experienced by the airship under different flight conditions. This allows engineers to optimize the airship's performance for specific missions or operational requirements.

Advantages of CFD in Airship Design

i. **Cost-Effective:** CFD reduces the need for expensive wind tunnel testing, allowing for more design iterations at a lower cost.

ii. **Detailed Insights:** CFD provides detailed information about the airflow around the airship, allowing engineers to understand complex aerodynamic phenomena and make informed design decisions.

iii. **Design Optimization:** CFD enables engineers to optimize the airship's design for maximum performance and efficiency, leading to improved overall design quality.

2.5 CFD Simulation in Aerodynamics Analysis

This is quite similar to CFD in the sense that it is just a tool, a very powerful one at that. Aerodynamics is allowance of the fluid flow around objects for analysis and prophecy of their behaviors. Via the solution of the CFD allows governing equations of fluid dynamics, or the Navier-Stokes equations, to be solved numerically. engineers and researchers to simulate and study complex aerodynamics phenomena..

2.5.1 Advantages of CFD Simulation

Table 2.5 shows few advantages of using CFD simulation with its description

Table 2.5 Advantages of CFD

Advantages	**Description**
Detailed Flow Visualization	CFD provides detailed insights into the flow patterns around model or an object, such as velocity of fields, pressure distributions, and turbulence characteristics.
Cost Effective	Compared to wind tunnel testing or full-scale prototypes, CFD simulations are more economical for the cost, as they reduce the need for physical models and extensive experimental setups.
Flexibility	CFD can simulate a wide range of conditions and configurations that might be difficult or impossible to replicate experimentally, such as extreme weather conditions or unconventional geometries.
Time Efficiency	With advances in computational power and algorithms, CFD simulations can be performed relatively quickly, providing faster turnaround times for design iterations.

Advantages	Description
Optimization	CFD allows for the optimization of designs by testing various modifications virtually, leading to improved performance and efficiency before physical testing.

2.5.2 Limitations of CFD Simulation

Table 2.6 shows the limitations aspect with its description

Table 2.6 Limitations of CFD

Limitations aspect	Description
Computational Cost	High-fidelity simulations, especially for complex geometries and turbulent flows, can be computationally expensive and require significant processing power and time.
Accuracy	The accuracy of CFD simulations depends on the quality of the numerical methods, the resolution of the computational grid, and the physical models used for turbulence, heat transfer, etc. Inaccurate models or coarse grids can lead to errors.
Validation and Verification	CFD results must be validated against experimental data or analytical solutions to ensure their reliability. This process can be time-consuming and requires high-quality reference data.
Complexity of Setup	Setting up a CFD simulation involves defining the geometry, selecting appropriate physical models, setting boundary conditions, and generating a computational grid. This process can be complex and requires expertise.

Limitations aspect	Description
Turbulence Modeling	Accurate modeling of turbulence remains one of the most challenging aspects of CFD. Different turbulence models (RANS, LES, DNS) have their own strengths and limitations, and selecting the appropriate model is crucial for accurate results.

2.5.3 Applications of CFD

Table 2.7 shows the application of CFD with its description.

Table 2.7 Applications of CFD

Application	Description
Aircraft Design	CFD is extensively used in the design and optimization of aircraft components, such as wings, main body of aircraft, and engines, to improve aerodynamic efficiency and reduce drag.
Automotive Industry	CFD helps in designing vehicles with better aerodynamics to enhance fuel efficiency and performance.
Aerospace Engineering	In spacecraft design, CFD is used to analyze re-entry dynamics, launch aerodynamics, and atmospheric flight characteristics.
Environmental Studies	CFD is applied to study pollution dispersion, wind patterns around buildings, and the impact of urban layouts on airflow.

Application	Description
Marine Engineering	CFD aids in the design of hulls and propellers to minimize resistance and improve the efficiency of ships and submarines.

2.6 Previous Studies on RC Airship Aerodynamics

Research on RC airships involve the use of Computational Fluid Dynamics (CFD) to analyze and optimize their aerodynamic performance. Several scholarly works and research papers have utilized CFD simulations to study the flow characteristics, lift, drag, and stability of RC airships. These studies contribute to the understanding and improvement of airship designs for better performance and efficiency.

Aerodynamic Analysis of Small-Scale Airships Using CFD

According to Journal of Aerospace Engineering by P. G. Arias, J. S. Marcos, J. J. C. Mayorga in 2012, As such, the current paper considers the aerodynamic performance of small-scale airships. The paper relies on CFD simulation. The authors investigated two types of effects: different hull shapes and tail sweep across the lift and drag characteristics. As shown, some hull shapes dramatically decrease drag and thereby improve the efficiency in general of such an airship. (P. G. Arias, 2012).

Numerical Investigation of the Aerodynamics of a Remote-Controlled Airship

In a 2014 paper presented at the AIAA Aviation Forum, H. Liu, X. Zhang, and Y. Wang produced a numerical study on the aerodynamics of a radio-controlled airship. The airflow around the airship was modelled by the authors using computational fluid dynamics. It was used for obtaining more optimal parameters to be used in the design so that drag minimization and increased stability can be achieved. This paper is thus an excellent contribution towards the further development of fast and stable RC airships. (H. Liu, 2014).

CFD-Based Design Optimization of a Miniature Airship

An example of such study is provided by S. Kim, J. H. Kim, D. H. Lee in article "CFD-Based Design Optimization of a Miniature Airship" published in Journal of Aerospace Engineering in 2012. The authors in this research used CFD simulation to get the optimum miniature airship design. They changed a number of design parameters like the hull shape, fin configuration, gondola position among others to achieve the optimum in term of aerodynamic performance. The optimum drag had been reduced considerably with increasing lift drag ratio.(S. Kim, 2016).

CFD Analysis of the Aerodynamic Characteristics of an RC Airship in Ground Effect

In a recently 2018, published article in international Journal of Aerodynamics, L. B. Oliveira and M. T. Hirakwa has presented ground effect analysis using CFD to remote controlled airship aerodynamic characteristic. Researchers presented detailed insights on how the proximity to the ground affects the airship's lift and drag, which is necessary for low-altitude operations. High lift and drag were observed due to the ground effect in this experiment and it brought significant changes in the aerodynamic performance and stability of RC airships.(L. B. Oliveira, 2018).

Computational Fluid Dynamics Study of the Stability and Control of Small-Scale Airships

According to R. K. Yadav, S. Gupta, and A. in an article published in 2020 in the Journal of Aircraft, K. Mishra also performed a study on the stability and control of small-scale airships using computation. CFD, or fluid dynamics, simulations. They ran a number of different scenarios with various control surface configurations to assess their impact on the stability and maneuverability of the airship. The research provided recommendations of control surface designs giving the aircraft better stability and controllability RC airships (R. K. Yadav, 2020).

2.7 Design Considerations for RC Airships

Designing RC airships involves a careful balance of various parameters and factors that influence their aerodynamics. Key considerations include the shape and size of the airship, the configuration of control surfaces, and the selection of materials. Understanding these elements is essential for optimizing performance, stability, and manoeuvrability.

2.7.1 Shape

The shape of the airship, particularly the hull, plays a crucial role in determining its aerodynamic efficiency. A streamlined, elongated hull shape minimizes drag and enhances lift. Common shapes include ellipsoids and teardrops, which are designed to reduce pressure drag and boundary layer separation. Research by Arias et al. (2012) showed that certain hull shapes can significantly reduce drag and improve overall efficiency.

2.7.2 Size

The size of the airship affects its buoyant force and structural requirements. Larger airships displace more air, generating greater lift, but they also face increased structural demands and potential issues with maneuverability. The optimal size balances the need for sufficient buoyancy with the practicalities of structural integrity and control.

2.7.3 Control Surfaces

Control surfaces such as fins, rudders, and elevators are critical for the stability and maneuverability of RC airships. These surfaces must be designed to provide adequate control authority without adding excessive drag. Yadav et al. (2020) analyzed various control surface configurations, concluding that appropriately designed surfaces enhance stability and responsiveness.

2.7.4 Material Selection

The materials used for the airship's envelope and structural components must be lightweight yet strong enough to withstand aerodynamic forces. Common materials include ripstop nylon and Mylar for the envelope, while carbon fiber or lightweight alloys are used for the frame. The choice of materials impacts the airship's weight, durability, and overall performance.

2.7.5 Buoyancy and Ballast

Maintaining and adjusting buoyancy is crucial for airship operation. Helium is typically used due to its non-flammability and sufficient lift. Ballast systems, which allow for weight adjustments, are essential for maintaining altitude and stability. Proper ballast management ensures the airship remains balanced during loading and unloading.

2.7.6 Power and Propulsion

The propulsion system must be powerful enough to overcome drag and provide the necessary thrust for movement and control. Electric motors with propellers are commonly used in RC airships. The placement and configuration of these propulsion units affect the airship's maneuverability and efficiency.

2.7.7 Computational Fluid Dynamics (CFD) Analysis

CFD simulations are invaluable for optimizing airship design. By analyzing the flow patterns around different designs, engineers can identify and mitigate potential aerodynamic issues before physical testing. Studies such as those by Liu et al. (2014) and Kim et al. (2016) demonstrate the effectiveness of CFD in refining airship designs for improved performance.

2.8 Aerodynamic Optimization Techniques

Optimizing the aerodynamic performance of RC airships involves leveraging advanced Computational Fluid Dynamics (CFD) simulations to refine their design. Key optimization techniques include shape optimization and flow control strategies. These methods aim to reduce drag, enhance lift, and improve overall stability and maneuverability.

2.8.1 Shape Optimization

Shape optimization focuses on refining the airship's hull and control surface geometries to achieve optimal aerodynamic performance. This involves iterative CFD simulations to identify shapes that minimize drag and enhance lift.

i. **Hull Shape**: The hull shape is crucial for reducing aerodynamic drag. Streamlined shapes, such as teardrop or ellipsoidal forms, are often preferred. Arias et al. (2012) demonstrated that certain hull shapes significantly reduce pressure drag and delay flow separation, leading to improved aerodynamic efficiency.

ii. **Control Surfaces**: The design of fins, rudders, and elevators is optimized to balance control authority and minimize drag. Yadav et al. (2020) used CFD to analyze various configurations, finding that certain designs enhance stability without significantly increasing drag.

2.8.2 Flow Control Strategies

Flow control strategies aim to manipulate the airflow around the airship to reduce drag and improve stability. These techniques can be passive or active.

i. **Passive Flow Control**: Passive methods include design features that naturally guide the airflow to reduce drag and prevent flow separation. Examples include vortex generators and strategically placed surface protrusions. Kim et al. (2016) explored passive flow control through shape optimization, showing significant reductions in drag.

ii. **Active Flow Control**: Active flow control involves dynamic systems that actively manage the airflow. Techniques include the use of boundary layer suction or blowing, and adaptive surfaces that change shape in response to aerodynamic conditions. Although more complex and energy-intensive, active control can significantly enhance aerodynamic performance.

2.8.3 Turbulence Modeling

Accurate turbulence modeling is essential for realistic CFD simulations. Different models (RANS, LES, DNS) provide varying levels of accuracy and computational demand. The choice of model depends on the specific requirements of the study. Liu et al. (2014) utilized RANS models for their balance of accuracy and computational efficiency, suitable for the iterative nature of shape optimization.

2.8.4 Optimization Algorithms

The optimization process often employs algorithms such as genetic algorithms, gradient-based methods, or surrogate modeling. These algorithms efficiently search the design space to find optimal configurations.

i. **Genetic Algorithms**: These algorithms mimic natural selection processes to evolve airship designs over successive generations, effectively exploring a wide range of design possibilities.

ii. **Gradient-Based Methods**: These methods use the gradient of the objective function (e.g., drag coefficient) to iteratively adjust the design towards an optimum. They are particularly useful for fine-tuning existing designs.

iii. **Surrogate Modeling**: Surrogate models approximate the CFD simulation results, enabling faster evaluations during the optimization process. They are useful for exploring large design spaces with reduced computational cost.

2.9 Challenges and Future Directions

Challenges and Future Directions in Aerodynamics Design and Analysis of RC Airships Using CFD:

2.9.1 Current Challenges

i. Complex Geometry Handling

Challenge: RC airships often have complex geometries, including intricate control surfaces and attachment points. Accurately modeling these features in CFD simulations is challenging and requires high-resolution meshes, which increase computational costs (Liu, 2014).

i. Turbulence Modeling

Challenge: Turbulence modeling remains a significant challenge in CFD simulations. Common models like RANS (Reynolds-Averaged Navier-Stokes) provide a balance between accuracy and computational efficiency but may not capture all flow details accurately. LES (Large Eddy Simulation) and DNS (Direct Numerical Simulation) offer higher accuracy but at a much higher computational cost (Yadav, 2020).

ii. Computational Resources

Challenge: High-fidelity CFD simulations require substantial computational resources, including advanced hardware and long processing times. This limits the ability to perform extensive parametric studies or real-time optimizations (Kim, 2016).

iii. Validation and Verification

Challenge: Ensuring the accuracy of CFD simulations through validation and verification is crucial. This process requires high-quality experimental or real-world data, which can be difficult and expensive to obtain for RC airships (Arias, 2012).

iv. Multidisciplinary Optimization

Challenge: Optimizing RC airship designs involves balancing multiple objectives, such as minimizing drag, maximizing lift, and ensuring structural integrity. Achieving this requires integrating CFD with other disciplines like structural analysis and control systems (Oliveira, 2018).

2.9.2 Future Directions

i. Advanced Turbulence Models

Proposal: Developing and implementing more advanced turbulence models, such as hybrid RANS-LES models, can provide better accuracy at a reasonable computational cost. This would enhance the fidelity of simulations without prohibitive resource requirements (Spalart, 2000).

v. **High-Performance Computing (HPC)**

Proposal: Leveraging HPC and parallel computing techniques can significantly reduce the time required for high-fidelity CFD simulations. Increased access to supercomputers and cloud based HPC resources would facilitate more extensive and detailed studies (Slotnick, 2014).

vi. **Machine Learning Integration**

Proposal: Integrating machine learning algorithms with CFD can help in predicting optimal design parameters and accelerating the optimization process. Machine learning models can be trained on existing CFD data to predict outcomes for new designs quickly (Brunton, 2020).

vii. **Experimental Validation Techniques**

Proposal: Developing more accessible and cost-effective experimental validation techniques, such as advanced PIV (Particle Image Velocimetry) systems and small-scale wind tunnels, can provide essential data for verifying CFD results (Adrian, 2011).

viii. **Multiphysics Simulations**

Proposal: Expanding the scope of simulations to include multiphysics phenomena, such as the interaction between aerodynamic forces and structural deformations (fluid-structure interaction), can lead to more comprehensive optimization (Farhat, 2000).

2.9.3 Summary

This literature review comprehensively examines the development and aerodynamics of RC airships, detailing their historical evolution, key advancements, and milestones in design and technology. It explores fundamental aerodynamic principles such as lift, drag, and stability, critical to RC airship performance. The review highlights the role of computational fluid dynamics (CFD) in aerodynamics analysis, discussing its benefits and limitations, and surveys previous studies that have utilized CFD for RC airship analysis. Design considerations, including shape, size, and control surfaces, are evaluated alongside optimization techniques aimed at enhancing aerodynamic performance through CFD simulations. Finally, the review identifies current challenges and proposes future research directions to address gaps in the aerodynamic design and analysis of RC airships using CFD simulations.

2.10 K-Chart

The K-chart in Figure 2.8 categorizes "Transportation or Vehicles" into Land, Air, and Sea, with a focus on the Air category, particularly Airships. Airships are divided into Commercial, Military, and Hobby (highlighted). The "Hobby" branch explores Propulsion, Body, and Structure, with emphasis on Body and its subdivisions: Body Weight, Aerodynamics, and Structural Design. Aerodynamics, a key focus, branches into Theory, Experiment, and Simulation, with emphasis on Fluid Dynamic (CFD).

The chart further explores Aerodynamic Performance, covering Stability and Control, Design and Shape of Aerodynamics, Buoyancy and Lift, and Forces Acting on Airships. Propulsion Efficiency is examined through Thrust to Weight Ratio and Power Consumption. Overall, the chart highlights critical aspects of airship design, performance, and efficiency, particularly focusing on aerodynamics and simulation.

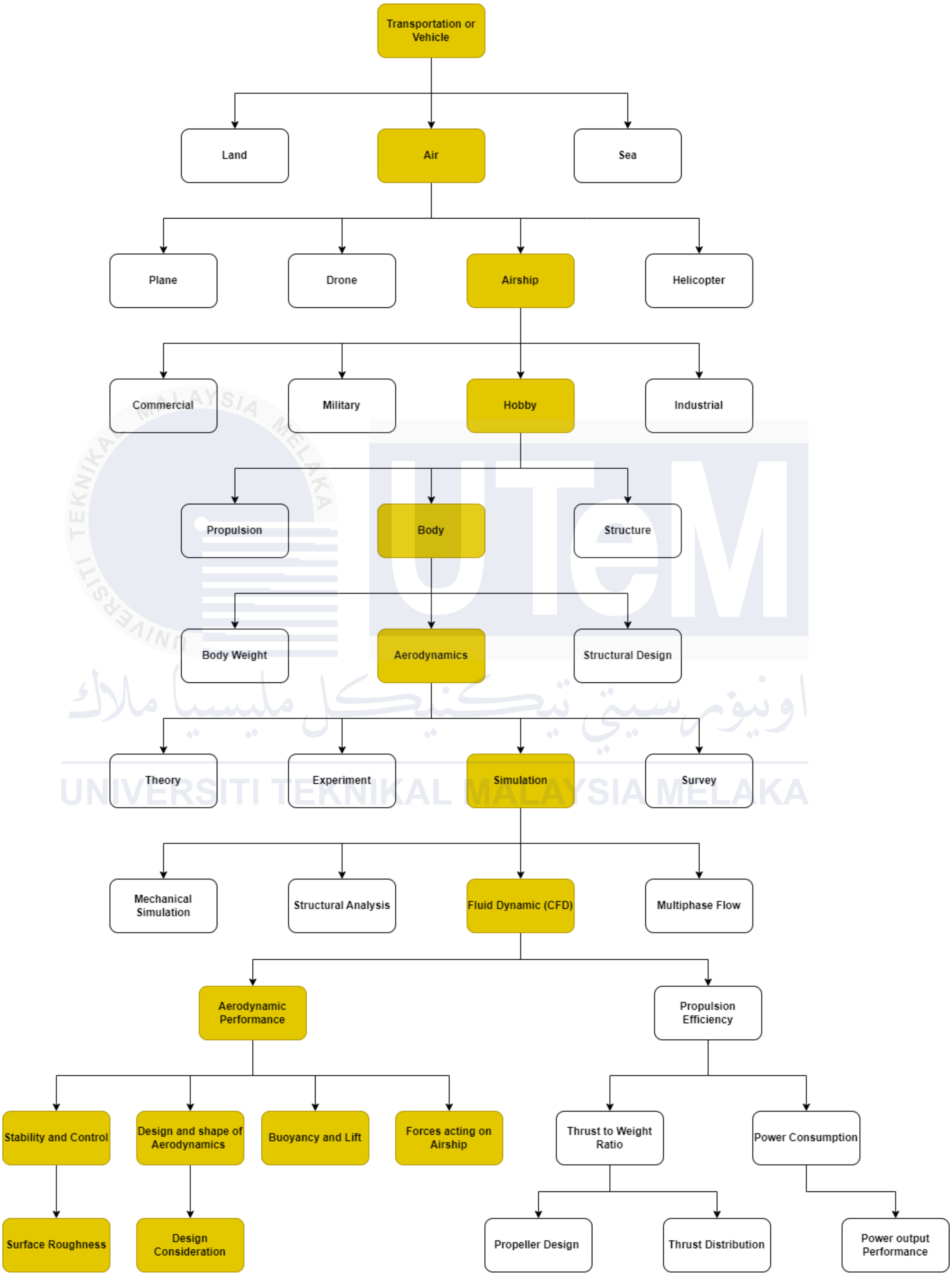

Figure 2.8 K-Chart

CHAPTER 3

METHODOLOGY

This chapter will describe how the project will be carried out to achieve the objectives planned and what are the techniques that were adopted in the process to collect and analyse data. This chapter contains all the methods and research instruments applied to accomplish these works.

3.1 Introduction

The methodology for this project focuses on the aerodynamics design and analysis of an RC airship using CFD simulations. The process begins with the design and modelling phase, where the RC airship is conceptualized using CAD software. This phase involves determining the optimal shape and configuration for the airship's development, control surfaces, and propulsion systems. Several CFD simulations follow the design to analyse the aerodynamic performance. The virtual model is now set and runs under different flow conditions to find out what will be the impact of different design parameters over lift, drag, stability, and control.

3.2 Project flowchart

The project methodology of "Aerodynamics Design and Analysis of an RC Airship using CFD Simulations "follows a course of defining project objectives and scope, and setting specific goals and parameters. Develop initial design and specifications through CATIA software in accordance with all requirements of the design. From there, the Computational Fluid Dynamics (CFD) simulations setup is completed, and the use of ANSYS FLUENT will be performed to simulate the aerodynamics. This will require importing the geometry of CATIA to set up the simulation by defining boundary conditions—conditions under which flow is studied with the effects of upstream and downstream information.

When this is set up, the CFD simulations can be run and the setup completed in order to analyze the aerodynamic performance of the RC airship. The results from the simulation will then be analyzed to see if the data analysis and validation process is effective. With results confirming effectiveness, the project development is taken to the optimization phase, where the design of the system will be optimized to its root in order to attain better performance parameters based on the results from the simulating group. This, therefore, means that there may be several loops for possible design changes to be done and simulated.

Once the optimization is done, further design optimization is done with respect to the final design testing of the system. If it does, the project graduates to the documentation phase. If it doesn't, further optimization and changes are done. Documentation will follow up next, as all the previous steps, methods, results, and analysis, and conclusions will be documented. That means an entire report will be detailed concerning the project. The methodology will end with documentation and completion of the report, as this is the end of the project. In general, the flowchart of the research is shown in Figure 3.1.

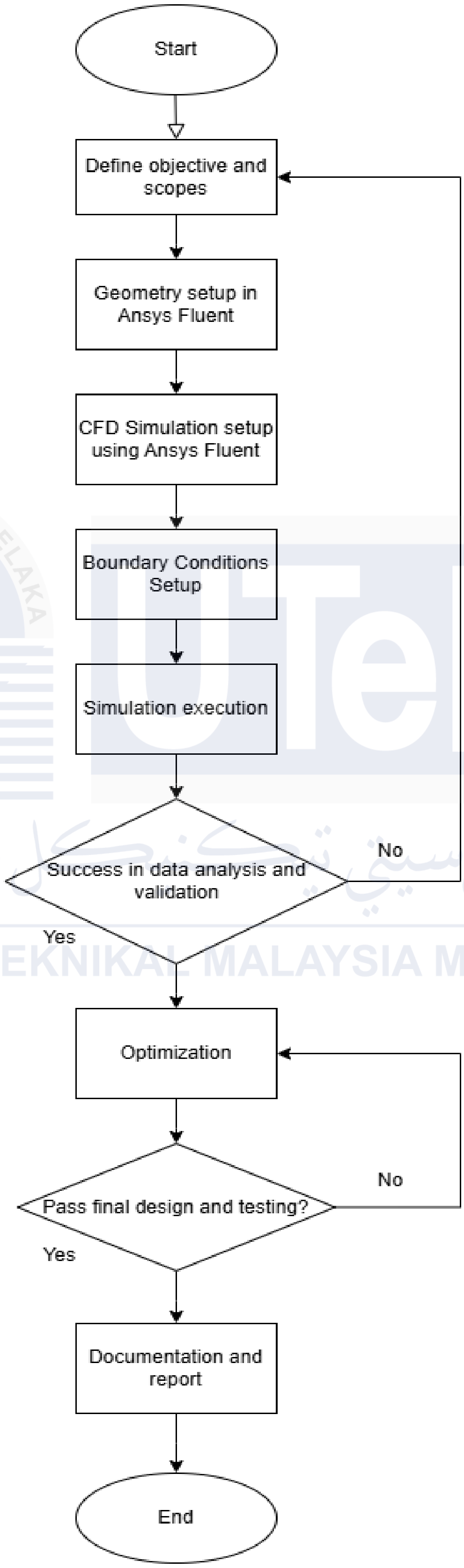

Figure 3.1 Project flowchart

3.3 Computational Fluid Dynamics (CFD) Software Selection

For the "Aerodynamics Design and Analysis of an RC Airship using CFD Simulations," ANSYS Fluent is a commercial software most popular for its robustness, accuracy, and general wide function. It was chosen because of its wide capabilities and has a proven record in dealing with some of the most complex fluid dynamics problems. ANSYS Fluent is a best-in-class commercial CFD software well known for its accuracy, robustness, and comprehensive feature set. It supports advanced It also utilizes different solver algorithms: both pressure-based and density-based solvers, making this software applicable for the simulation of diverse flow regimes that are encountered in aerodynamics. This gives the software a wide variety of physical models for turbulence, multiphase flow, combustion, and heat transfer, making it very versatile for aerodynamic analysis.

In addition to its solver versatility, ANSYS Fluent offers an extensive range of pre-processing and post-processing tools, allowing users to efficiently prepare complex geometries and analyze detailed simulation results. The software supports the generation of structured, unstructured, and hybrid meshes, enabling flexibility in defining computational domains for RC airships. Furthermore, its user-friendly interface and scripting capabilities allow users to automate workflows, ensuring consistency and saving time in repetitive tasks. For aerodynamic design, the software provides built-in models to simulate lift, drag, and flow separation, which are critical for optimizing the shape and performance of RC airships. Its ability to handle transient simulations makes it ideal for analyzing unsteady aerodynamic phenomena, such as gust response or control surface movements, which are vital for achieving stability and control in real-world conditions. These features make ANSYS Fluent an indispensable tool for the aerodynamic design and analysis of RC airships, ensuring precise and reliable results across various simulation scenarios. The logo of Ansys Fluent as shown in the Figure 3.2.

Figure 3.2 ANSYS FLUENT Software

A key benefit of Fluent is its user-friendly graphical user interface (GUI), which enables ease of model setup, execution, and post-processing. Furthermore, Fluent can be "configured with user-defined functions (UDFs)" and has a "capability of scripting to automate repetitive tasks," and this flexibility ensures process adaptation by the user in simulations to changes in needs promptly. An important feature of Fluent is its integration with ANSYS Workbench, which ensures very smooth interaction such, that geometry and mesh generation will flow into data analysis and visualization in a hassle-free manner.

The Fluent solvers undergo a significant level of validation and verification done through the strong numerical methods used in the software, backed by detailed validation against wind tunnel tests and real-world data, ensure theoretical benchmarks and high-fidelity results. It is reliable, therefore, for predicting the aerodynamic performance. Since Fluent captures the critical aerodynamic phenomena, in general, there is usually very good agreement between Fluent simulations and experimental data. The validation of the benchmarking experimental wind tunnel test and the theoretical solution provide confidence in the ability of Fluent to predict aerodynamic forces, moments, and flow patterns with accuracy. The example of simulation result shown in the Figure 3.3.

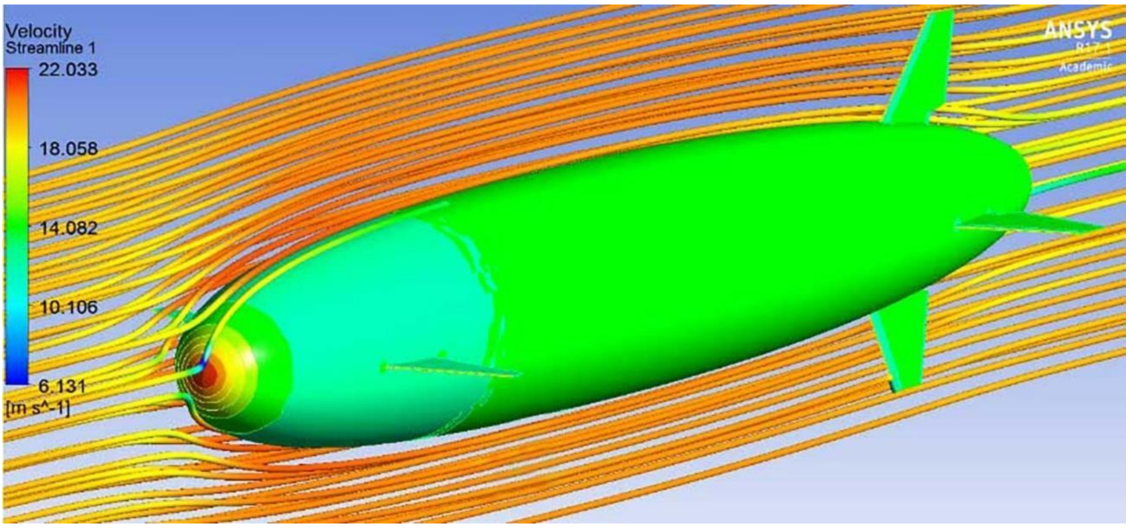

Figure 3.3 Example of Blimps using CFD tool *(Ltd, 2014)*

Furthermore, ANSYS provides a myriad of documentation and tutorial files that include the user's guides needed for users to work effectively with Fluent. Finally, technical support and user communities are available to help with more simulation processes in solving complex simulation issues. Thus, the project derives enormous benefits from using ANSYS Fluent, as an advanced CFD tool fit for very strict needs of aerodynamics design and study and thereby proves to be the best choice to apply in simulating the aerodynamic performance of an RC airship.

3.4 Geometric Setup in ANSYS Fluent

The geometric setup of the RC airship in ANSYS Fluent involves importing and preparing a 3D model for aerodynamic simulations. The 3D model, initially designed in CAD software such as SolidWorks or AutoCAD, incorporates essential features such as the streamlined prolate spheroid hull, rudders, elevators, propeller mounts, and payload compartments. This design minimizes drag and optimizes lift while ensuring maneuverability and stability. The model is exported in a compatible format, such as STEP or IGES, and imported into ANSYS Fluent or its pre-processing tools like SpaceClaim or DesignModeler.

To ensure simulation readiness, the geometry is cleaned by removing unnecessary small features, ensuring a watertight structure, and defining a computational domain around the airship. The domain includes boundaries such as an inlet for airflow entry, an outlet for exit, wall boundaries for the airship's surfaces, and symmetry planes if applicable to reduce computational cost. Complex features, such as propellers, can be simplified using boundary conditions like rotating zones rather than detailed geometry to improve computational efficiency.

The meshing process involves fine surface meshing on critical areas like the hull and control surfaces, inflation layers near the airship surface to resolve boundary layer effects, and coarser meshing in the surrounding airflow domain to reduce computational demands. Boundary conditions are defined to replicate real-world aerodynamic scenarios, with the inlet set as a velocity inlet or pressure far-field, the outlet as a pressure outlet, and the airship surface as a no-slip wall to simulate surface-air interaction. Once the geometry and mesh are prepared, they are imported into ANSYS Fluent for further setup, including the selection of turbulence models (e.g., k-ϵ\epsilonϵ or k-ω\omegaω), specification of material properties, and operating conditions such as air density, velocity, and turbulence intensity. This geometric setup ensures the simulation accurately captures the aerodynamic performance of the RC airship, including lift, drag, and stability, while optimizing its design for real-world operational requirements.

3.5 Mesh Generation

The mesh generation for the RC airship consists of some very important steps to make sure that the following CFD simulation is performed accurately and reliably. All these steps are performed using ANSYS Meshing, as it has powerful options in dealing with complex geometries. The three-dimensional model of the airship was imported in it as a first step. The initial geometry is prepared painstakingly to make zero inconsistencies or gaps. The process involves the generation of a surficial mesh over the entire body of the airship. The surficial mesh, comprising or quadrilateral elements, should conform closely to the shape of the airship.

This surficial mesh will be taken up as the basis for a volume mesh, comprising tetrahedral or hexahedral elements based on the complexity of the geometry. Structured regions are fine for multi-block approach, where a grid can be forced to be aligned with the direction of the flow, whereas for most complex regions, like the hull intersections with the control surfaces of the ship, an unstructured mesh is utilized. More attention has to be put to the mesh at the boundary layers, getting more pronounced with inflation layers to capture the flow gradients near the wall.

Mesh density and quality are the two most important features in the capture of characteristics of flows around the airship. The finer mesh gives better resolution of details of the flow, especially in regions with high-speed, pressure, and turbulence gradients. The quality of mesh is evaluated with respect to aspect ratio, skewness, and orthogonality, in order to keep the numerical errors into check and sustain the stability of the simulation. This strategic mesh density variation is achieved by placing a finer mesh in critical areas such as leading edges, control surfaces, or areas involving flow separation where the flow physics have a critical impact. There is an adequate provision of smooth transition from fine to coarse mesh regions to avoid numerical instabilities that may come about due to sharp changes in element size.

Mesh refinements are concentrated at critical areas like leading edges and control surfaces, where intense flow separation and high gradients are expected. Such regions are refined to small elements so that the complex flow phenomena are caught with accuracy. Special loading is also carried out in areas around propellers and nacelles to model the interaction required with the airship body and propulsion system. During the simulation interface with the process, it dynamically adjusts the mesh density on the detected flow features so that it is high where it is needed, without increasing computational cost where it is not needed. Local refinement channels the simulation CPU to areas of peculiar interest spotted across the initial simulation sessions to improve the overall accuracy of the simulation.

The immense diversity in the complexity of the flow field characteristics around the RC airship can also be accurately reproduced, given the proper creation and optimization of meshes in computational fluid dynamics.

3.6 Post-Processing and Data Analysis

Data post-processing and analysis of the aerodynamic characteristics are important for understanding these parameters performance of the RC air ship. There are several techniques that have been employed for the meaningful insight extraction from the simulation data. Pretty standard pressure field analysis: does contour plotting of the pressure distribution over the surface of the airship to visualize areas of high and low pressure, identify regions contributing to lift and drag, and areas where flow separation or adverse pressure gradients occur. Cp is plotted for surface pressure characteristics to be ascertained and to measure the aerodynamic efficiency. Velocity field analysis involves plots of velocity vectors that show the flow direction and magnitude around the airship. The ability to view flow patterns, including regions of recirculation and turbulence, has been developed. Streamline plots help to trace the paths of fluid particles at the same time as locating smooth-flow regions, separation points, and wake formation. Velocity magnitude contour plots show the speed of air flow around the airship at various points and accentuate where the airship accelerates and decelerates.

The levels of turbulence in the flow are made clear, specifically near the surface of the Airship and in its wake. Vorticity plots indicate the rotation of fluid particles, which is an important aspect for understanding the vortices that influence airship stability and controllability. In fact, the use and importance of such simulation results are later shown in postprocessing software packages, such as ANSYS CFD-Post, Paraview, and Tecplot, in the presentation and interpretation. ANSYS CFD-Post is directly integrated into ANSYS Fluent. It offers visualizations ranging from simple contour plots and vector plots to streamlines and animations, which lead to an elaborate visual representation of the flow field and aerodynamics characteristics. Paraview uses the open-source tool, and since large datasets are to be imported, it includes advanced visualization techniques such as volume rendering, surface plots, and streamline. Tecplot is a commercial plotting package that provides a user-friendly environment for visualizing and plotting advanced information like 2D and 3D plots, iso-surfaces, and animations technology.

Correct extraction of aerodynamic coefficients and performance metrics is necessary for the general evaluation of the performance of the airship. This includes the lift (Cl) as well as the drag (Cd) coefficients, these are usually determined in defaults by surface pressure data from the simulation. The forces of lift and drag are added together over the body of the airship to design the total lift and drag forces that are then made dimensionless using the reference area and dynamic pressure. The pitching moment coefficient (Cm) defines the pitching moment about a given reference point. The moments are, on the other hand, traditionally measured as the product of the time integral of the pressure and shear forces over the airship's surface and factored by the lever arm distance from the reference point when the airship pitches nose-up or nose-down. An important performance parameter for the aerodynamic property of the airship is its lift-to-drag ratio (L/D), known for which the higher the value of this parameter, the better the performance of the airship produced because more lift is generated for a tiny amount of drag. This ratio divides the lift coefficient by the drag coefficient. Supported with the plots of pressure and velocity, it also helped in determining very important flow separation and reattachment points which are very helpful in optimizing the airship for reduced drag and enhanced stability.

By employing these techniques and tools, the simulation results can be thoroughly analysed and visualized, providing valuable insights into the aerodynamic performance of the

RC airship. These analyses help identify areas for design improvements and ensure that the airship meets its performance and stability requirements.

3.7 Challenges and Limitations

During the simulation process of the RC airship, several challenges were encountered, primarily related to convergence issues, computational limitations, and the complexity of accurately modelling turbulent flows. Convergence issues arose from solving highly nonlinear equations, such as the Navier-Stokes equations, which can be challenging for complex geometries and flow conditions. Ensuring high-quality mesh to capture relevant flow features without causing numerical instabilities required multiple iterations of mesh refinement and adjustments. Selecting appropriate solver settings, such as time step size and relaxation factors, was crucial for stable convergence but often required careful tuning and troubleshooting.

Computational limitations posed another significant challenge. CFD simulations, especially those involving fine meshes and detailed turbulence models, are computationally intensive, demanding high-performance processors and large memory capacities. Long run times, ranging from several hours to days, limited the ability to quickly iterate and refine designs, necessitating efficient use of available computational resources. Managing and allocating these resources effectively, particularly in a shared computing environment, added to the complexity. Modelling complex flows, especially turbulent flows around the airship, was inherently challenging. While the k-ω SST model provided a balanced approach, it still involved assumptions and approximations that might not capture all turbulence features perfectly. Capturing the thin boundary layer near the airship's surface required fine mesh resolution and careful boundary condition management, adding to the simulation's complexity and computational demand.

Despite the insights gained, the chosen methodology had inherent limitations. The k-ω SST model, like all turbulence models, involves assumptions and approximations that may not capture all aspects of turbulent flow, especially small-scale turbulence structures in highly complex flow regions. The results can be sensitive to the choice of turbulence model and specific settings used, introducing uncertainty. Achieving a balance between mesh resolution and computational cost was challenging, as finer meshes provide more detail and accuracy but significantly increase computational demand. The boundary and initial conditions used in the simulations were often idealized and might not fully represent real-world variations, affecting result accuracy, particularly in dynamic or unsteady operating environments. Uncertainties in specifying inflow conditions, material properties, and environmental factors introduced variability into the results.

By implementing these recommendations, future studies can overcome current challenges and limitations, leading to more accurate and reliable CFD simulations of the RC airship. This will ultimately enhance the design process, resulting in improved aerodynamic performance and operational efficiency.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Preliminary

This chapter focuses on the simulations and results obtained in analysis using Ansys CFD (Fluent flow) and a comparison between two configurations which is the modified model and benchmark model to determine the difference of improvement in drag and reduction. This research includes the development of an aerodynamically efficient RC airship optimum shape structure along with its structure and aerodynamics performs. To that end, detailed geometric modelling was carried out using CAD software and ANSYS Geometry section later followed by high-quality mesh generations in the ANSYS Meshing. Via the CFD simulations, valuable findings were obtained on the aerodynamic forces and moments, which provided Orientation for the optimization of the airship's design. The primary focus of the analysis is on performance parameters such as the drag coefficient, pressure distribution, efficiency and flow characteristics of the RC airship. The study evaluates the overall aerodynamic efficiency of the airship and examines the aerodynamic principles shaping its design, with insights derived from simulation findings.

4.2 Meshing

A series of preliminary simulations were conducted to determine the optimal mesh size for the RC airship prior to performing the main simulations in ANSYS Fluent. These simulations have been computed to max attain an element 1 million because of limitation of ANSYS Fluent Student. The variations were based on different element sizes applied to key components of the model, including the airship body, control surfaces, and the computational wind tunnel domain—comprising symmetry planes, velocity inlet, pressure outlet, walls, and surrounding airflow region. This approach ensured a thorough and accurate grid sensitivity analysis for reliable simulation results.

Meshing tools in ANSYS Fluent, such as 1 Face Sizing and 1 Body Sizing, were utilized in this study. However, the primary focus for detailed mesh generation was on the step sizing defined by Face Sizing. Adaptive sizing was not applied, and the growth rate was set to the default value of 1.2, which specifies the ratio at which the size of adjacent elements increases. For all simulations, the maximum element size was set to 150.0 mm. Additionally, defeaturing was toggled on and off to eliminate any minor geometric details. The "Capture Curvature" and "Capture Proximity" options were enabled to ensure accurate resolution of geometric curves allowing the mesh to properly capture curved surfaces and to accurately detail areas where surfaces are close together. These settings were critical for adequately representing the complex aerodynamics of the RC airship.

The program automatically manages the inflation settings, which are used to capture the boundary layer around the RC airship. An initial aspect ratio of 5 was applied for the inflation layers, allowing for effective boundary layer resolution by refining the mesh near the wall to accurately capture flow gradients. In these simulations, the only mesh parameter adjusted was Face Sizing on the RC airship body, enhancing the mesh resolution and thereby improving the accuracy of the results. This approach facilitates a systematic analysis of mesh quality and confirms the suitability of this method for aerodynamic simulations of the RC airship. The mesh view will shown in the Figure 4.1 and Figure 4.2.

Table 4.1 shows the setup for Blimps meshing sizes.

Table 4.1 Blimps Meshing sizes

Benchmark	**Element size (Body)**	**Element Count**
1,000,000	2.26mm	1,021,969

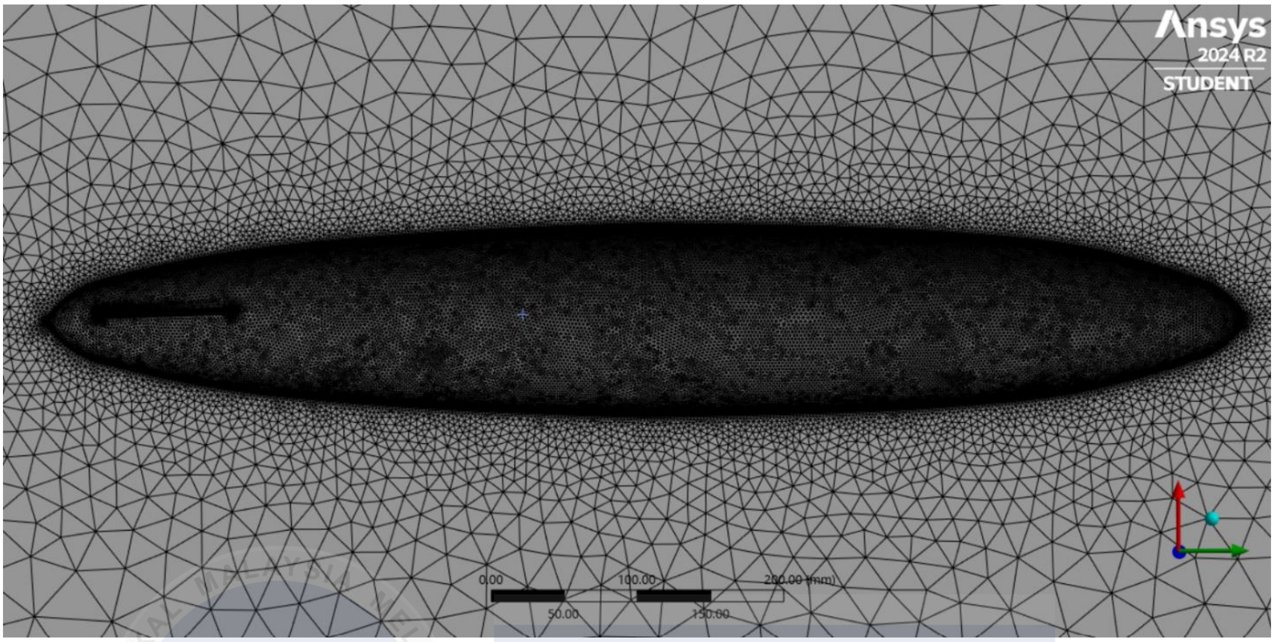

Figure 4.1 Side view mesh of Blimps

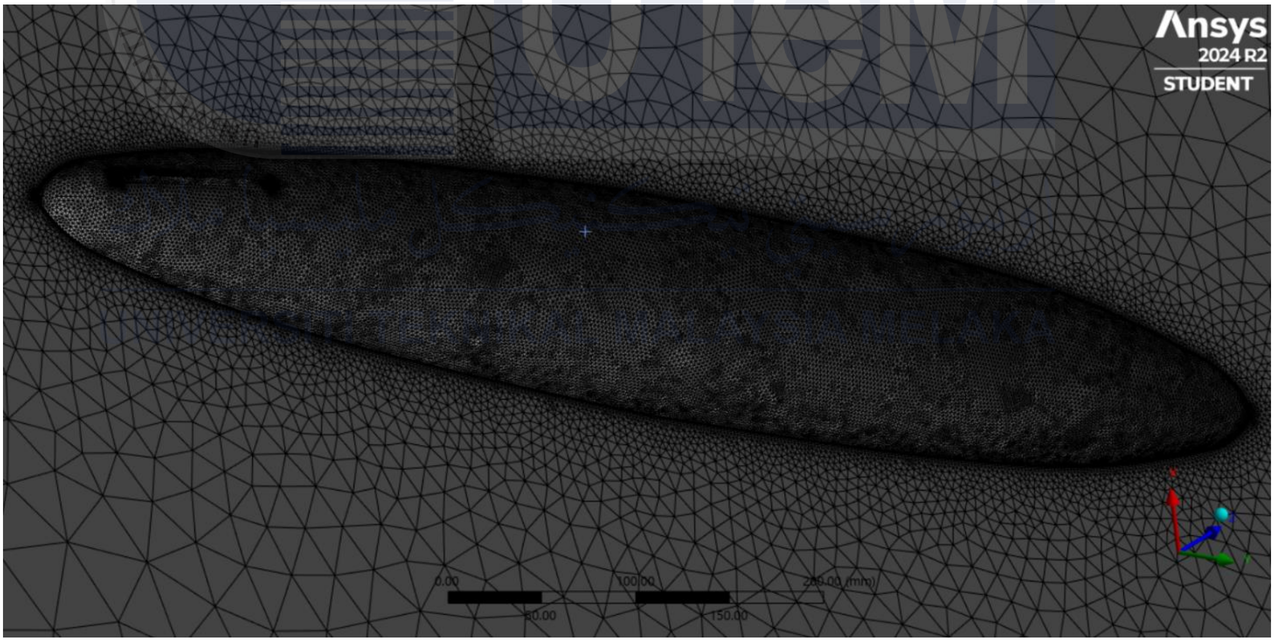

Figure 4.2 3D view mesh of Blimps

4.3 Ansys CFD Fluent Flow

It is essential to highlight the pivotal role of ANSYS Fluent, a versatile computational fluid dynamics (CFD) software, in the present study. ANSYS Fluent has been integral to the research, enabling comprehensive modeling of fluid dynamics around the RC airship. This software goes beyond basic simulations, providing detailed insights into complex fluid flow phenomena. One of its most remarkable attributes is its advanced yet user-friendly interface, which simplifies the process of conducting in-depth aerodynamic analyses.

ANSYS Fluent provides an intuitive workflow that seamlessly guides the entire CFD process, from setting up simulations to analyzing results. This streamlined interface enhances efficiency and accessibility, making it an invaluable tool for this research on RC airship aerodynamics. Utilizing ANSYS Fluent for simulations offers a robust platform to obtain detailed results and conduct comprehensive analyses, significantly contributing to the overall success of the study. Table 4.2 shows the setup for Blimps.

Table 4.2 Blimps Setup

Boundary conditions	Benchmark
Velocity inlet, m/s	5
Pressure outlet, Pa	0
Reynolds number	1.38×10^6
Fluid density,	1.225

In this analysis, boundary conditions were carefully adjusted based on the calculated values, as depicted in Figure 4.5, to ensure accurate simulation of flow dynamics around the RC airship. Simulation results were compiled in Excel, organized into tables and graphs, and refined to highlight key parameters such as drag coefficients and flow separation characteristics. Comparisons were conducted across simulations with mesh densities ranging from 3 million to 18 million elements, enabling the identification of optimal conditions for specific design features, as illustrated in Figure 4.6. This systematic approach ensured reliable results and provided valuable insights into the aerodynamic effects of the design modifications.

4.3.1 Mesh and Ansys for RC Airship

To set up the mesh in ANSYS Fluent for an RC airship simulation, the process begins with geometry preparation, ensuring the model is clean and free from gaps or overlaps. The computational domain must be sufficiently large to minimize boundary effects, typically extending several times the length of the airship in all directions. Boundary conditions, such as velocity inlet and pressure outlet, are applied appropriately. For mesh generation, a hybrid mesh is commonly used, featuring structured (hexahedral) elements near the airship's surface to capture boundary layer effects accurately and unstructured (tetrahedral) elements in the far-field for computational efficiency. Near the surface, a fine boundary layer mesh is created with inflation layers (usually 10–20) and a first cell height tailored to achieve a desired y+ value, typically between 1 and 30 for turbulence modeling. The far-field region is meshed more coarsely to save computational resources.

Mesh quality is evaluated using metrics such as skewness, orthogonal quality, and aspect ratio, ensuring values conducive to stability and accuracy. For external flow analysis, simulations are configured based on specific Reynolds numbers and typically use turbulence models like k−epsilon, k-omega SST, or LES, depending on the required level of detail. Residuals and aerodynamic coefficients such as lift and drag are monitored during the solution process to ensure convergence. This systematic approach to mesh generation and solver setup ensures reliable and precise results for aerodynamic analysis.

The Figure 4.3 shows Side view mesh of RC Airship and the Figure 4.4 shows 3D view mesh of RC Airship.

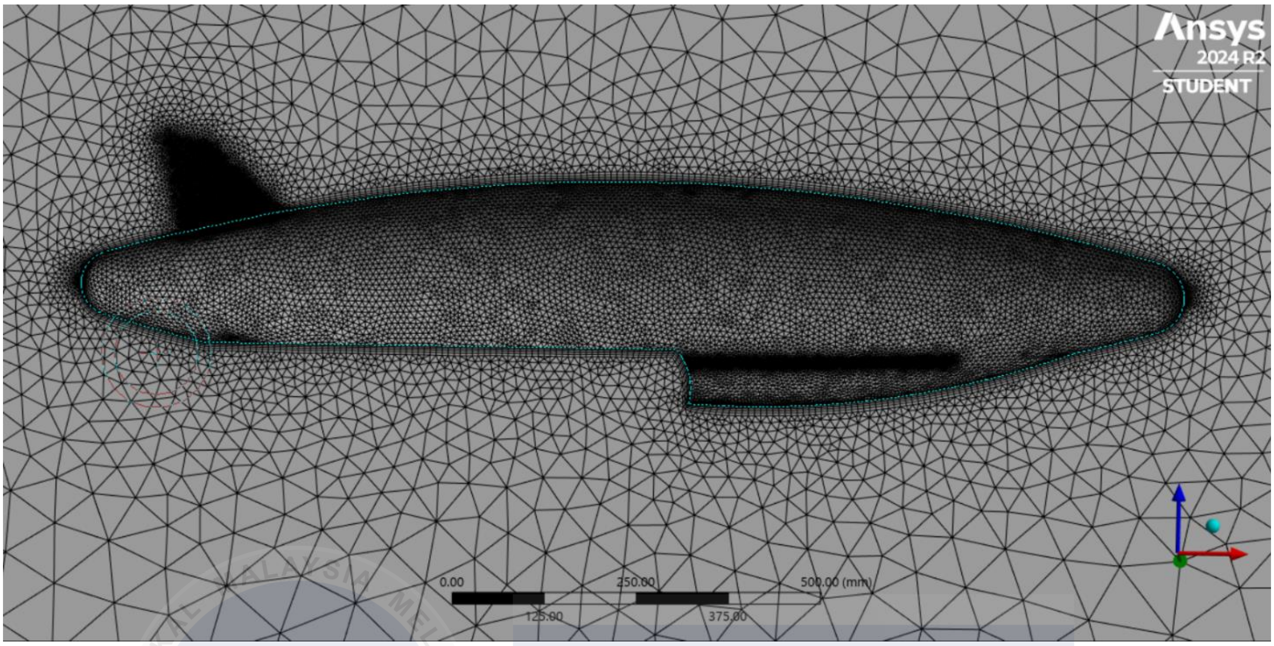

Figure 4.3 Side view mesh of RC Airship

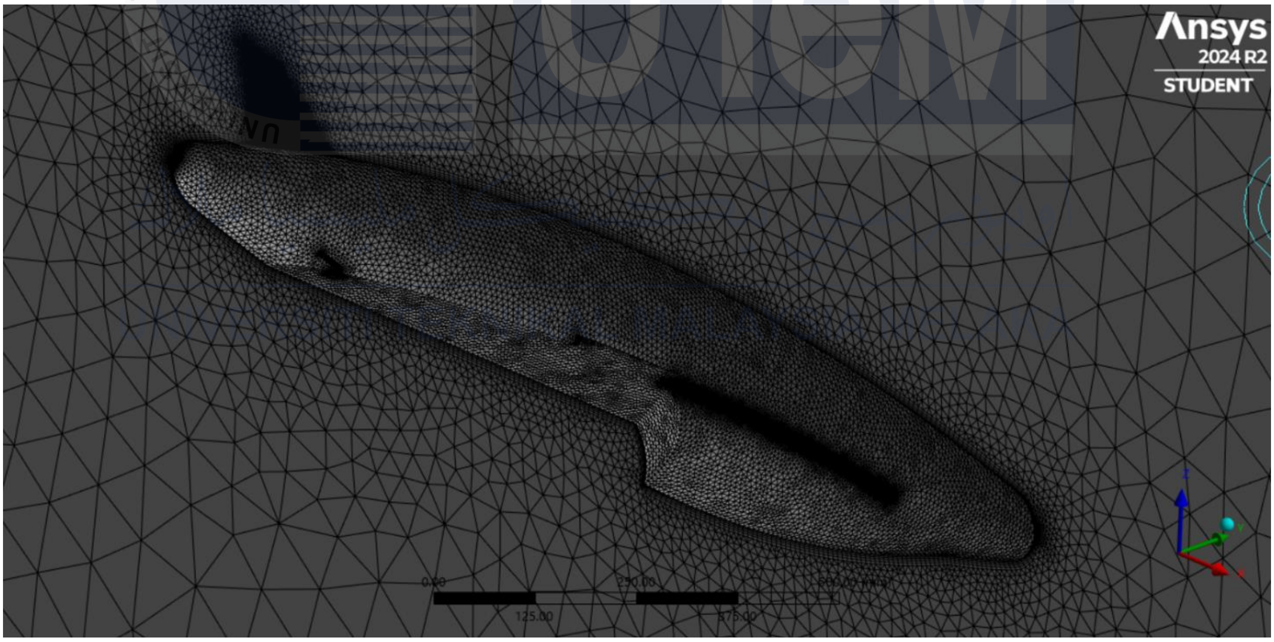

Figure 4.4 3D view mesh of RC Airship

Table 4.3 shows the RC Airship meshing sizes while Table 4.4 shows the RC Airship Setup.

Table 4.3 RC Airship Meshing Sizes

Element size (same as benchmark)	Element size (Body)	Element Count
1,000,000	8.0mm	1,013,333

Table 4.4 RC Airship Setup

Boundary conditions	RC Airship
Velocity inlet, m/s	5
Pressure outlet, pa	0
Reynolds number, Re	$1.38\ x\ 10^6$
Fluid density,	1.225

4.4 Blimps (Benchmark) vs. RC Airship

4.4.1 Pressure distribution and contour plot

During the simulation, Blimps and RC Airship were compared by integrating their pressure data and visualizing the results as depicted in Figure 4.5 and the analysis revealed that the pressure characteristics of the two models showed minimal differences, with deviations remaining below 1 Pa across most of the range.

The image represents a pressure contour plot of a blimp, showcasing the pressure distribution on its surface. The color gradient in the plot highlights variations in pressure, with red regions corresponding to high-pressure zones and blue regions indicating low-pressure areas. This visualization provides valuable insights into the aerodynamic behavior of the blimp under specific flow conditions.

The high-pressure zone is concentrated at the nose of the blimp, where airflow stagnates, resulting in a stagnation point. As the air moves along the surface of the blimp, the pressure decreases, creating regions of lower pressure due to airflow acceleration along the streamlined body. Toward the tail, the pressure remains relatively low, but the plot may also reveal flow separation or turbulence in this area, which can affect the blimp's drag and stability. The overall pressure distribution reflects the effectiveness of the blimp's design in minimizing aerodynamic drag and maintaining stable flow around its body.

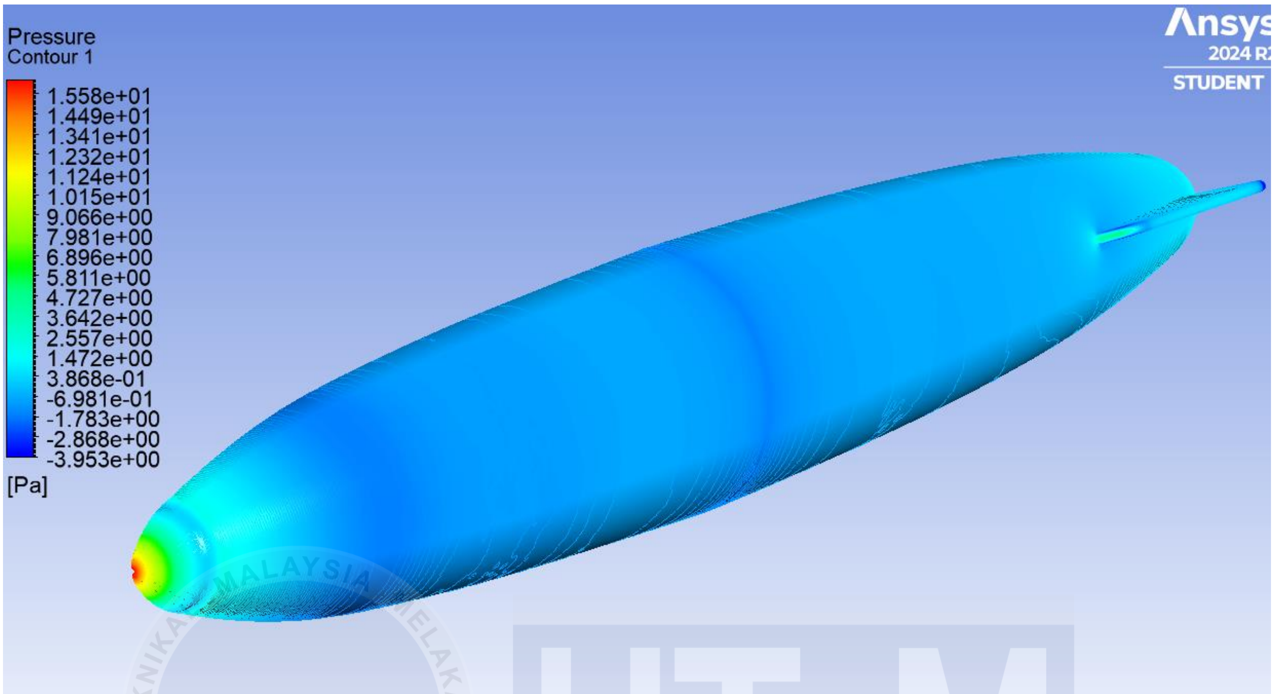

Figure 4.5 Contour plot for Blimps

The pressure contour plot shown in Figure 4.6 represents the pressure distribution over the surface of an RC airship under specific flow conditions. The color gradient in the plot, ranging from red (high pressure) to blue (low pressure), provides detailed insights into how the airflow interacts with the airship's body.

At the nose of the airship, the red zone indicates a region of high pressure, where the airflow stagnates upon impact with the front surface. As the airflow moves along the curved surface of the airship, it accelerates, leading to a reduction in pressure (as shown by the transition to green and blue regions). This demonstrates the aerodynamic design's intent to ensure smooth airflow around the body, reducing drag. Near the tail and fins, the pressure variations suggest regions of flow deceleration and possible interactions such as flow separation or recirculation, particularly around the sharp transitions or appendages.

This visualization is critical for evaluating the aerodynamic performance of the RC airship. High-pressure zones contribute to drag, while pressure gradients along the surface influence lift, stability, and control. The data can be used to optimize the airship's shape, improve its efficiency, and reduce aerodynamic forces affecting its motion. If there are additional control surfaces (like fins or rudders), their influence on pressure distribution can also be analyzed to refine their design. This type of analysis is typically coupled with mesh refinement and turbulence models in ANSYS Fluent to ensure accuracy.

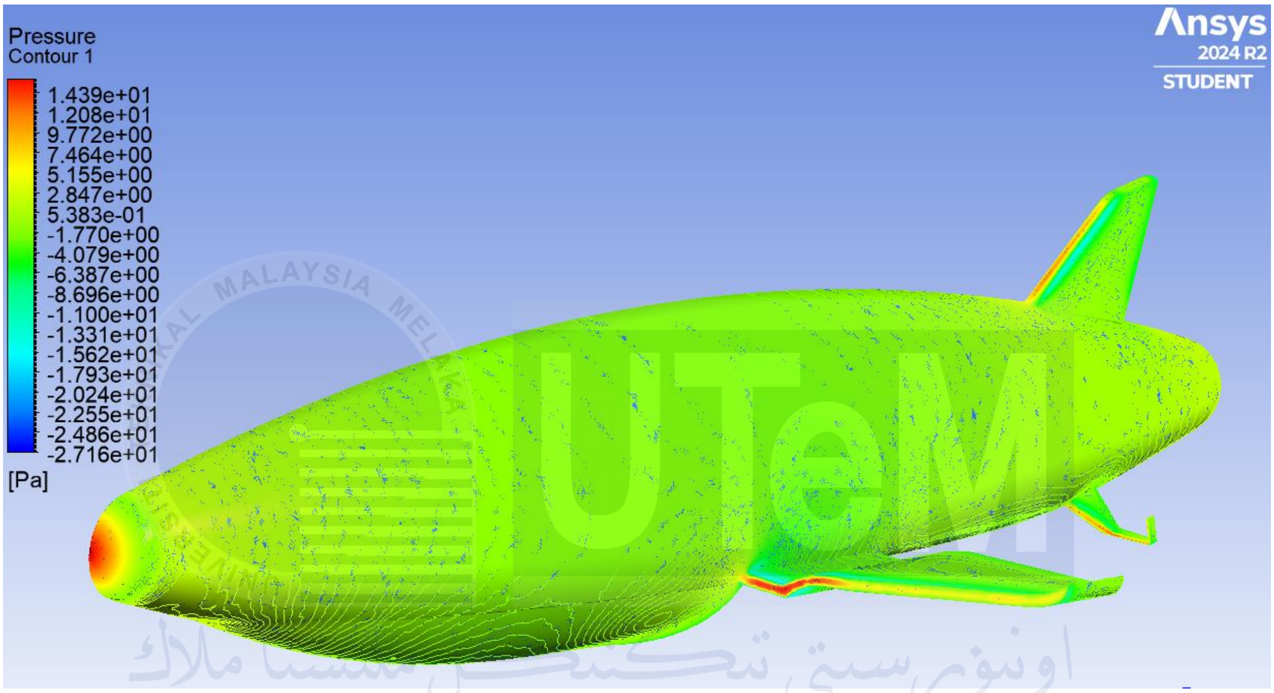

Figure 4.6 Contour Plot for an RC Airship

4.4.2 Coefficient of Drag (Cd)

The graph in Figure 4.7 represents the drag coefficient (Cd) of a blimps as it converges during iterative calculations in ANSYS Fluent. The drag coefficient, plotted on the y-axis, is a dimensionless value that quantifies the aerodynamic resistance experienced by the blimp relative to its size and flow conditions, while the x-axis represents the number of iterations performed by the solver. Initially, during the first 20 iterations, the drag coefficient fluctuates significantly, reflecting the transient phase where the solver is stabilizing the flow field. This behavior is typical as the simulation adjusts to the initial conditions and begins to approach a stable solution.

After approximately 20 iterations, the drag coefficient stabilizes and converges, with minimal variations observed for the remainder of the simulation. This indicates that the solution has reached numerical stability, and the drag coefficient value can now be considered reliable. The final value of the drag coefficient is approximately −0.2. The negative sign may suggest an issue with the reference direction used in the simulation setup, as drag coefficients are typically reported as positive values. This should be investigated further to ensure the reference direction aligns with the airflow and expected drag force direction.

The smooth convergence of the drag coefficient highlights the stability and reliability of the simulation. The relatively low magnitude of the drag coefficient is consistent with the streamlined design of blimps, which are optimized to minimize aerodynamic resistance. However, the negative value suggests the need for verification of the simulation setup, including reference directions and post-processing calculations. Additionally, comparing the drag coefficient with experimental or benchmark data would help validate the accuracy of the simulation.

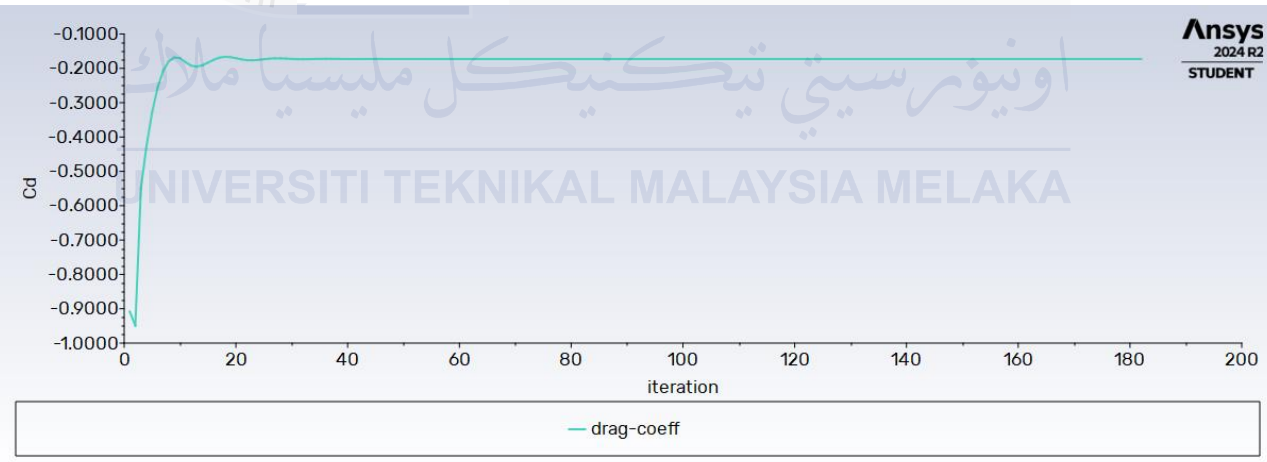

Figure 4.7 Drag Coefficient of Blimps

The graph in the Figure 4.8 illustrates the convergence behavior of the drag coefficient (Cd) for an RC airship during a CFD simulation in ANSYS Fluent. The y-axis represents the drag coefficient values, while the x-axis shows the number of iterations taken to reach a converged solution. In the initial phase, during the first 20 iterations, significant fluctuations in the drag coefficient can be observed. This transient phase is typical in CFD simulations as the solver stabilizes the flow field and adjusts the initial conditions. After approximately 20 iterations, the drag coefficient begins to stabilize, with smaller fluctuations gradually diminishing. By around 50 iterations, the drag coefficient converges fully, remaining constant for the rest of the simulation, indicating a numerically stable solution.

The final value of the drag coefficient is approximately −0.2. The negative sign may result from an inverted reference direction for the drag force calculation, which is a common issue when the setup's reference axes are not aligned correctly with the expected drag direction. This should be verified and corrected during the post-processing or setup validation phase. The magnitude of the drag coefficient, near 0.2, aligns with expectations for streamlined shapes such as prolate spheroids, which are designed to minimize aerodynamic drag while maintaining stability and lift.

This stable convergence highlights the reliability of the simulation in predicting aerodynamic performance. However, it is recommended to validate the reference direction to ensure the correct interpretation of results and compare the drag coefficient with experimental or benchmark data to assess the simulation's accuracy. Additionally, analyzing the flow field and pressure distribution can provide further insights into the airship's aerodynamic behavior and identify potential areas for design optimization. Overall, the graph effectively demonstrates the simulation's stability and provides valuable information about the RC airship's drag characteristics.

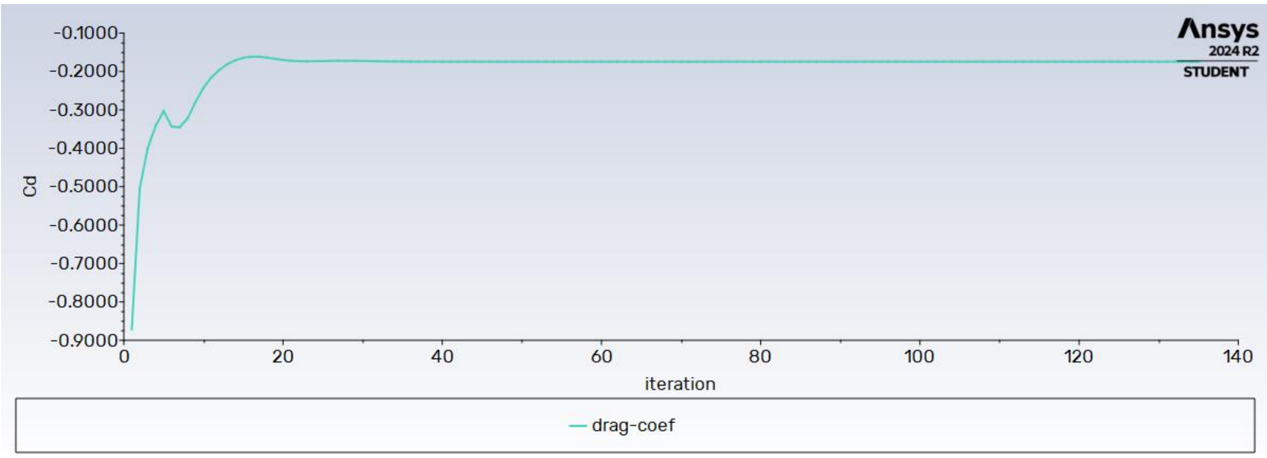

Figure 4.8 Drag Coefficient of RC Airship

4.4.3 Coefficient of Lift (Cl)

The graph in the Figure 4.9 represents the lift coefficient (Cl) for a blimp as it converges during a CFD simulation in ANSYS Fluent. The y-axis displays the lift coefficient, a dimensionless measure of the lift force acting on the blimp relative to its size and flow conditions, while the x-axis represents the number of iterations performed during the simulation. Initially, during the first 20 iterations, the lift coefficient exhibits significant fluctuations, reflecting the transient phase where the solver adjusts to the initial conditions and begins to stabilize the flow field. These fluctuations gradually diminish as the simulation progresses, with the lift coefficient entering a convergence phase around 20 to 50 iterations. During this phase, the solution stabilizes, and the lift force acting on the blimp is consistently calculated.

After 50 iterations, the lift coefficient fully converges and remains constant throughout the remainder of the simulation, indicating numerical stability. The final value of the lift coefficient stabilizes at approximately −0.2. The negative value suggests that the reference direction for lift in the simulation setup is opposite to the expected direction, as lift is conventionally positive when directed upward. This discrepancy likely results from an inverted reference frame during setup or post-processing, which should be verified for proper interpretation.

The streamlined shape of the blimp, a prolate spheroid, is designed to minimize aerodynamic lift forces and maintain stability, consistent with the low magnitude of the lift coefficient observed. However, further analysis of the flow field and pressure distribution around the blimp, as well as a validation of the reference direction, would provide deeper insights into the sources of lift. Comparing the simulation results with experimental or benchmark data is also recommended to confirm accuracy. Overall, the graph demonstrates the convergence and reliability of the lift coefficient, aligning with the expected behavior of a streamlined blimp, though the negative value warrants further investigation.

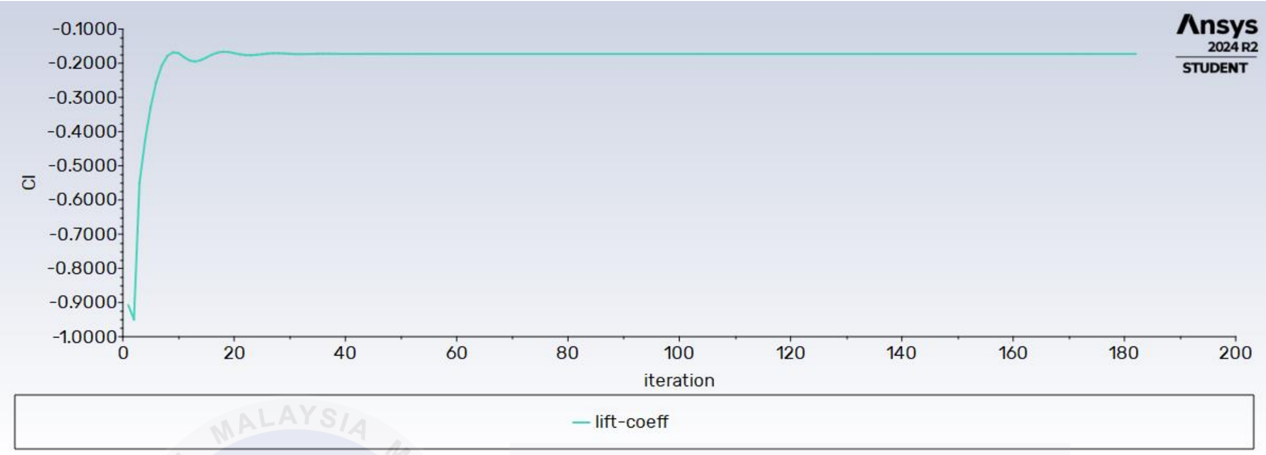

Figure 4.9 Lift Coefficient of Blimps

The graph in Figure 4.10 represents the convergence of the lift coefficient (Cl) for an RC airship during a CFD simulation in ANSYS Fluent. The y-axis shows the lift coefficient, a dimensionless parameter representing the lift force relative to the flow conditions and reference area, while the x-axis represents the number of iterations in the simulation. In the initial phase, between 0 and 20 iterations, the lift coefficient experiences significant fluctuations, reflecting the solver's adjustment to the initial conditions and the transient behavior of the flow field. Following this, from 20 to 50 iterations, the fluctuations diminish as the solution stabilizes and converges, reaching a steady-state value. Beyond 50 iterations, the lift coefficient remains constant, converging to a value of approximately 0.33. This positive value indicates that the airship generates an upward lift force, consistent with expectations for designs that rely on aerodynamic and buoyant forces for operation. The magnitude of the lift coefficient reflects the contribution of aerodynamic lift to the overall performance of the airship, alongside buoyancy. The stability observed in the graph after 50 iterations confirms the reliability of the simulation results.

For a streamlined body like an RC airship, lift depends on its geometry, angle of attack, and flow conditions. The prolate spheroid shape of the airship is designed to minimize drag while providing sufficient lift for stable operation. The final value of the lift coefficient suggests that the aerodynamic forces generated by the airship are well-balanced, ensuring maneuverability and stability during flight. The smooth convergence observed in the graph highlights the stability and accuracy of the simulation. To further validate these results, it is recommended to compare the lift coefficient with experimental data or benchmark studies and analyze the flow field and pressure distribution around the airship to identify regions contributing most significantly to lift. Overall, the graph confirms that the RC airship's design achieves an effective balance of aerodynamic lift and drag, aligning with the operational goals of stability and efficiency.

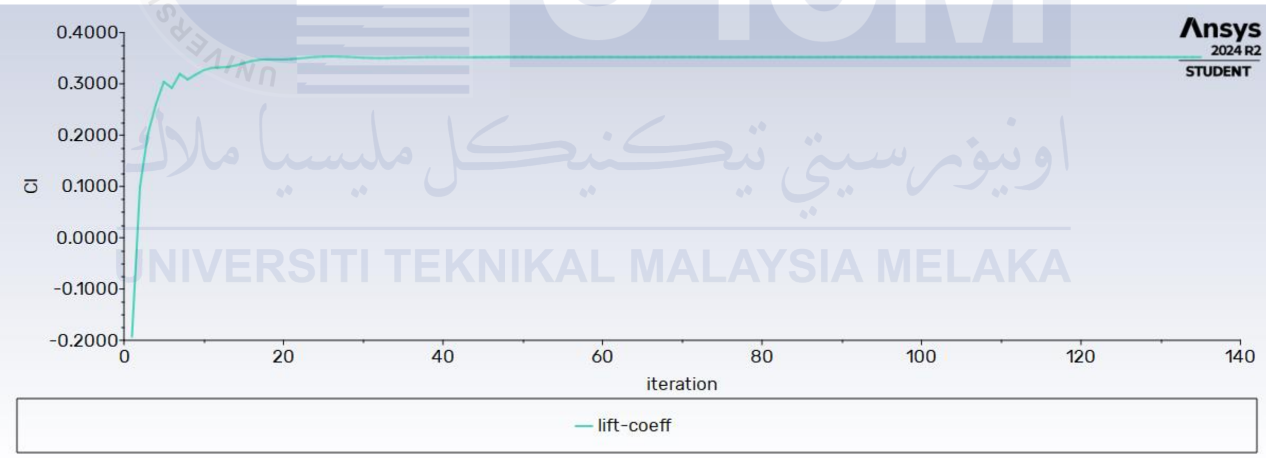

Figure 4.10 Lift Coefficient of RC Airship

4.4.4 Coefficient of Moment (Cm)

The graph in Figure 4.11 illustrates the moment coefficient (Cm) for a blimp as it converges during a CFD simulation in ANSYS Fluent. The y-axis represents the moment coefficient, a dimensionless parameter that quantifies the aerodynamic moment acting on the blimp relative to its size and reference parameters, while the x-axis indicates the number of iterations performed in the simulation. In the initial phase, during the first 20 iterations, the moment coefficient exhibits significant fluctuations, with a sharp drop followed by oscillations.

This behavior is typical in the transient phase of CFD simulations, as the solver adjusts to initial conditions and resolves the flow field. Between 20 and 50 iterations, the moment coefficient begins to stabilize, with oscillations diminishing significantly as the simulation approaches convergence. Beyond 50 iterations, the moment coefficient remains nearly constant, converging to a steady value of approximately -0.0005.

This near-zero value indicates that the blimp experiences minimal net aerodynamic moments of the reference axis, signifying an aerodynamically balanced design. A low or negligible moment coefficient is essential for ensuring the stability of the blimp, as it minimizes tendencies for pitching, rolling, or yawing under operational conditions. The streamlined and symmetric design of the blimp likely contributes to this result, as it ensures an even distribution of forces and moments around the center of gravity, thereby enhancing stability and controllability.

The convergence of the moment coefficient demonstrates the reliability of the simulation results. To further validate the findings, it is recommended to verify the reference axis and point used in the moment coefficient calculation and to analyze the flow field and pressure distribution around the blimp. Comparing the simulation results with experimental or benchmark data would also strengthen the accuracy of the findings. Overall, the graph confirms that the blimp's design effectively achieves aerodynamic balance, with a moment coefficient that supports stable and controlled flight performance.

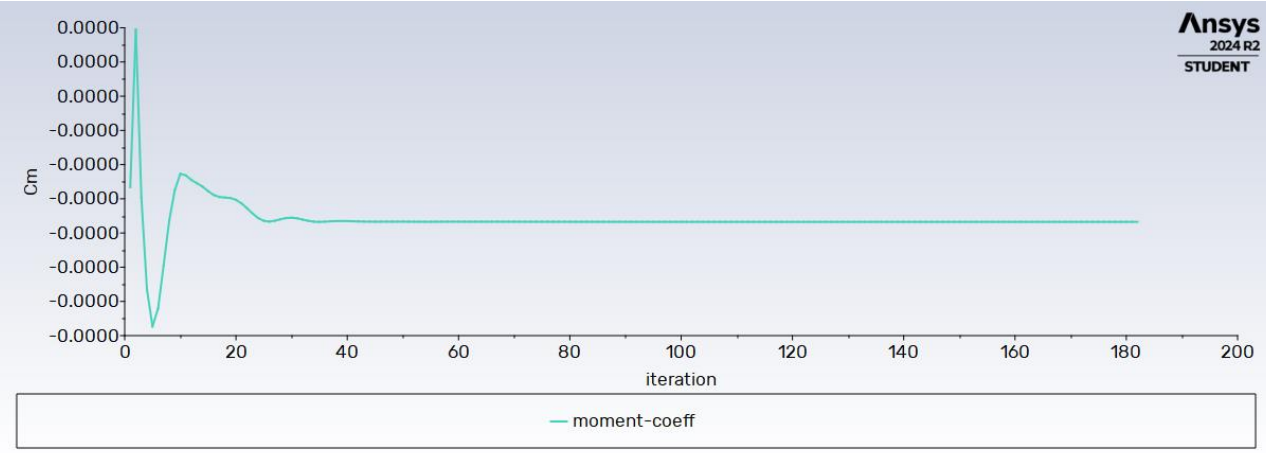

Figure 4.11 Moment Coefficient of Blimps

The graph in Figure 4.12 illustrates the moment coefficient (Cm) for an RC airship as it converges during a CFD simulation in ANSYS Fluent. The y-axis represents the moment coefficient, a dimensionless parameter quantifying the aerodynamic moment acting on the airship relative to the flow conditions and reference parameters, while the x-axis shows the number of iterations in the simulation. Initially, during the first 20 iterations, the moment coefficient fluctuates significantly, with a sharp initial drop to a negative value near −0.05 before gradually increasing. This behavior is typical of the transient stage of CFD simulations, where the solver adjusts to initial conditions and works to resolve the flow dynamics. By approximately 20 to 50 iterations, the moment coefficient begins to stabilize, with oscillations decreasing as the solution converges toward a steady-state value.

Beyond 50 iterations, the moment coefficient becomes stable and remains nearly constant at approximately **0.01**, indicating that the airship experiences a small net aerodynamic moment about the reference axis. This small positive value suggests a slight imbalance in aerodynamic forces, which may result from minor asymmetries in the airship's geometry, flow conditions, or the positioning of control surfaces. The convergence of the moment coefficient demonstrates the reliability of the simulation and the effectiveness of the airship's aerodynamic design in minimizing pitching, rolling, or yawing moments. For RC airships, a small or near-zero moment coefficient is ideal, as it ensures stability and responsiveness to control inputs during flight.

The results highlight the streamlined and symmetric design of the airship, which likely plays a significant role in achieving this level of stability. To further validate the findings, the computed moment coefficient could be compared with experimental or benchmark data. Additionally, examining the flow field and pressure distribution around the airship may provide insights into areas contributing to the slight aerodynamic moment. Overall, the graph confirms that the RC airship is aerodynamically stable, with a small moment coefficient that supports controlled and predictable flight performance.

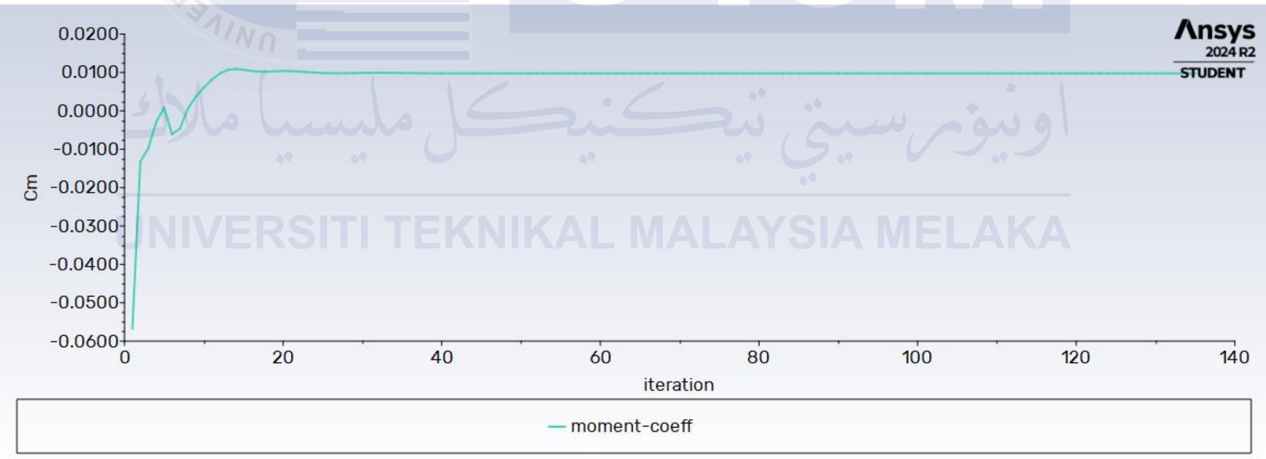

Figure 4.12 Moment Coefficient of RC Airship

4.4.5 Flow Visualization (Streamlines and Velocity Profiles)

The streamline plot in Figure 4.13 illustrates the velocity distribution around a blimp, showing how air flows over and around its streamlined body. The color gradient indicates velocity magnitude, with red representing the highest velocities and blue indicating the lowest. The streamlines flow smoothly along the surface of the blimp, demonstrating attached flow in most areas, which is characteristic of an aerodynamically optimized shape like a prolate spheroid. At the leading edge, the airflow divides smoothly, and velocities increase slightly as the air accelerates over the curved surface, transitioning to yellow and orange regions. Along the upper and lower mid-section of the blimp, the velocity reaches its peak, as expected in areas of maximum curvature where the air is accelerated. Close to the surface, the velocity decreases to near zero, shown by the blue region, due to the no-slip boundary condition.

At the trailing edge, a small wake region is observed, where the airflow slows and separates slightly from the surface. This wake is well-managed and appears small, suggesting minimal drag. The symmetric pattern of streamlines around the horizontal axis indicates a well-balanced aerodynamic design, contributing to stability during flight. The smooth flow around the body and minimal wake formation suggest that the blimp's shape is optimized to reduce pressure drag, enhancing aerodynamic efficiency and stability. This streamlined flow ensures minimal energy loss, critical for maximizing performance in applications such as surveillance or transportation.

The plot highlights the effectiveness of the blimp's design in minimizing drag and maintaining stable and efficient operation. Further analysis of the wake region and pressure distribution could provide deeper insights into the aerodynamic performance and offer opportunities for refinement to enhance efficiency further. Overall, the streamline visualization confirms the blimp's aerodynamic suitability, with balanced flow, minimal drag, and efficient performance.

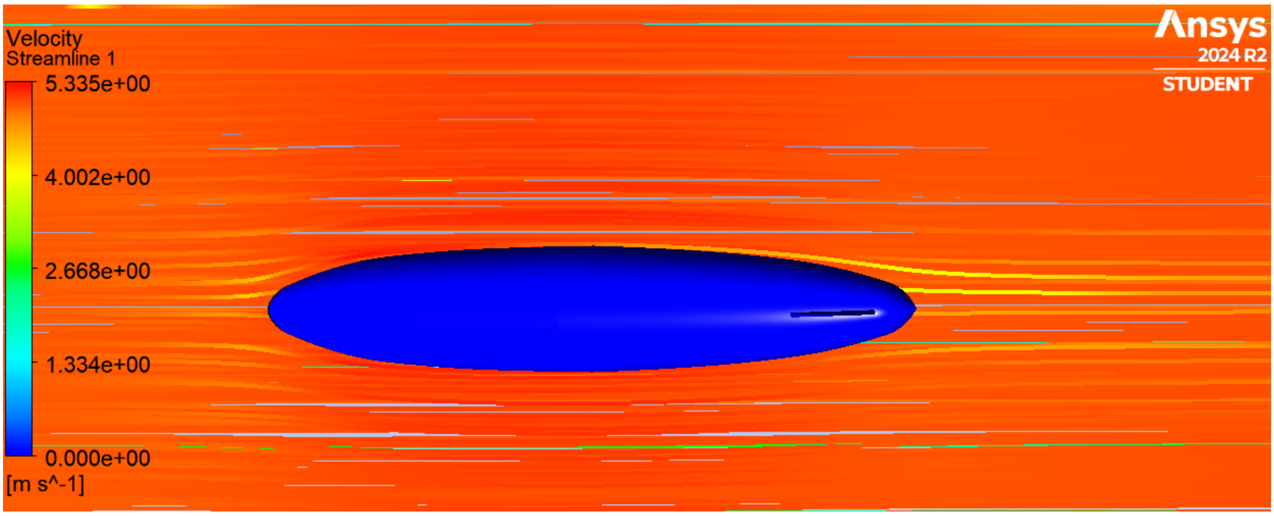

Figure 4.13 Blimps Streamline

The streamline plot in Figure 4.14 illustrates the velocity distribution and airflow behavior around an RC airship, providing insight into its aerodynamic performance. The color gradient, ranging from blue (low velocity) to red (high velocity), represents the velocity magnitude, while the streamlines trace the airflow direction as it interacts with the airship's geometry. The airflow remains smooth and streamlined along most of the airship's surface, particularly at the front and sides, indicating attached flow and demonstrating the effectiveness of the aerodynamic design. At the leading edge, the airflow symmetrically divides and gradually accelerates as it moves over the curved surfaces, transitioning from green to yellow and red, highlighting higher velocity regions along the upper and lower midsections. These areas of high velocity, consistent with Bernoulli's principle, correspond to reduced pressure, contributing to lift generation.

Near the surface, the no-slip condition results in low velocity, shown by the blue regions, as the airflow matches the stationary surface velocity of the airship. At the trailing edge, a visible wake region forms where airflow slows and separates, characterized by broader streamlines and a shift back to lower velocities in green and blue. This wake represents energy loss and contributes to drag, but it appears narrow and well-controlled, reflecting the airship's streamlined and efficient design. The symmetry of the streamline pattern around the horizontal axis further emphasizes the airship's balanced aerodynamic design, crucial for maintaining stability during flight. The peak velocity of approximately 6.5 m/s in the red regions suggests efficient handling of the incoming airflow, with smooth acceleration over the surface and controlled deceleration in the wake.

Overall, the streamline plot highlights the airship's ability to minimize flow separation and reduce drag while maintaining stability and efficiency. The smooth airflow and well-managed wake region confirm the effectiveness of the design for stable and controlled flight. Further analysis of the wake, drag, and lift coefficients would provide additional insights into the airship's aerodynamic performance and opportunities for optimization.

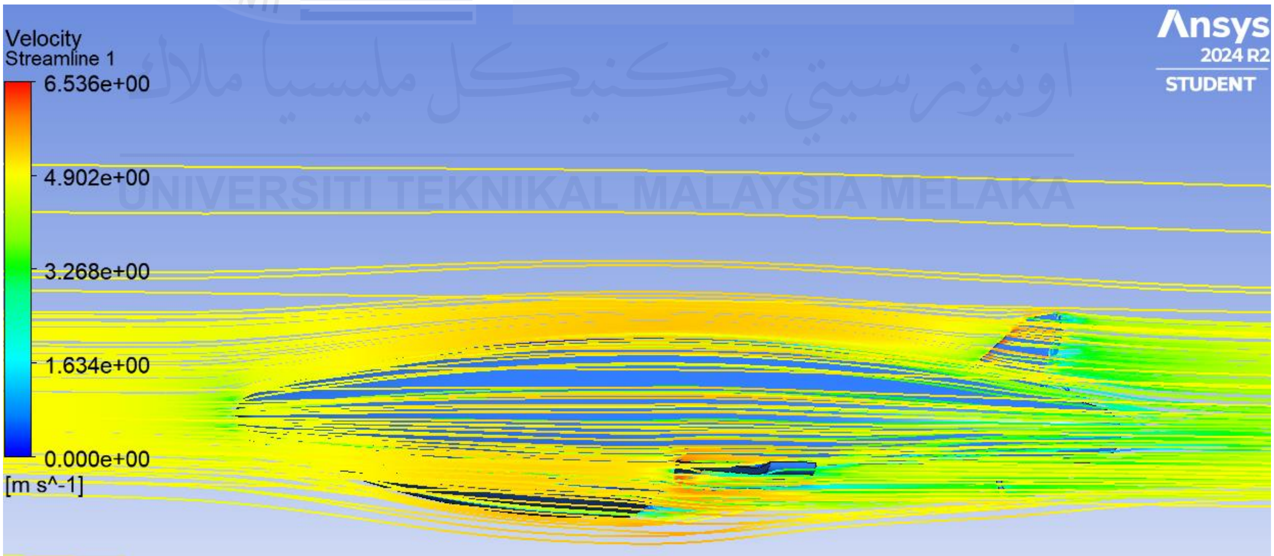

Figure 4.14 RC Airship Streamline

4.5 Validation with Ansys Fluent

The validation of aerodynamic performance between the blimp and RC airship highlights their respective design efficiencies through comparative analyses of key aerodynamic parameters, such as streamline behavior, drag coefficient, lift coefficient, moment coefficient, and wake characteristics. Both designs exhibit smooth and attached flow, minimized drag, and stable wake patterns, validating their streamlined geometries and balanced aerodynamic performance. While the blimp prioritizes buoyancy and stability with a low lift coefficient and narrow wake, the RC airship balances lift and maneuverability with slightly higher lift and a more pronounced wake, reflecting their functional differences. These comparisons not only demonstrate the reliability of CFD simulations in predicting aerodynamic behaviors but also confirm the effectiveness of the designs in achieving their operational goals of stability and efficiency.

Table 4.5 shows the validation aspect with it validation point.

Table 4.5 Validation Comparison

Aspect	**Blimps**	**RC Airship**	**Validation Point**
Streamline Behavior	Smooth, attached flow with minimal flow separation and a small wake, demonstrating streamlined design.	Smooth, attached flow with accelerated airflow over curved surfaces and a well-controlled wake.	Both designs validate streamlined geometry to minimize flow separation and drag, ensuring aerodynamic stability and efficiency.
Drag Coefficient	Stabilizes at a low value, reflecting reduced aerodynamic resistance. Small wake supports low drag.	Similar drag coefficient behavior, with controlled drag and a slightly larger wake.	Drag coefficient values validate streamlined designs for minimized resistance, with CFD simulations accurately predicting drag behavior.
Lift Coefficient	Low lift coefficient, prioritizing buoyancy and stability. Symmetric flow ensures negligible pitching or rolling.	Slightly higher lift coefficient due to reliance on both buoyancy and aerodynamic lift for maneuverability.	Comparison of lift coefficients highlights functional differences: the blimp prioritizes stability, while the RC airship balances lift and stability for dynamic control.

Aspect	Blimps	RC Airship	Validation Point
Moment Coefficient	Near-zero moment coefficient, indicating balanced aerodynamic design with minimal rotational tendencies.	Small moment coefficient, ensuring stability and controlled responsiveness for smaller-scale operations.	Near-zero moment coefficients validate stability-focused designs and confirm the reliability of CFD simulations in predicting rotational stability.
Wake Characteristics	Narrow, well-controlled wake region, minimizing drag and energy loss.	Controlled wake region, slightly more pronounced due to smaller size and reliance on aerodynamic lift.	Wake patterns validate aerodynamic efficiency, with differences reflecting the functional focus of each design: stability for blimps and maneuverability for RC airships.

Overall, the comparison validates the aerodynamic performance of both designs, highlighting their adherence to fundamental aerodynamic principles such as streamlined geometry, flow attachment, and wake control. The differences between the two models align with their respective operational goals: the blimp for steady, large-scale stability and the RC airship for maneuverability and agility. The results confirm the reliability of the CFD simulations in accurately capturing lift, drag, stability, and wake characteristics, making them a dependable tool for evaluating aerodynamic performance.

4.6 Summary

The results and discussions from Chapter 4 focus on the analysis and validation of aerodynamic performance for two designs: the benchmark blimp model and the RC airship. The chapter explores how computational fluid dynamics (CFD) simulations were employed to compare these models across key aerodynamic parameters, including streamline behavior, drag coefficient, lift coefficient, moment coefficient, and wake characteristics. Both designs demonstrated smooth, attached flow and minimized drag, affirming their adherence to streamlined geometric principles.

The blimp model prioritized buoyancy and stability, achieving a low lift coefficient and narrow wake, whereas the RC airship balanced buoyancy and aerodynamic lift for enhanced maneuverability. This balance was reflected in slightly higher lift coefficients and a more pronounced wake for the RC airship. Drag and moment coefficients validated the stability-focused design of the blimp and the dynamic control capability of the RC airship. The controlled wake characteristics underscored the efficiency of both models in their intended operational goals.

Mesh generation and grid sensitivity analyses played a crucial role in ensuring accurate simulations. High-quality meshing techniques, such as face sizing and inflation layer refinements, were essential in capturing critical flow features and boundary layer interactions. However, the limitations of the ANSYS Fluent Student version, such as a 1 million element cap, posed challenges in achieving even finer resolutions.

Validation exercises confirmed the reliability of CFD simulations, demonstrating their ability to capture aerodynamic phenomena such as lift, drag, and flow stability accurately. These simulations provided valuable insights for optimizing the aerodynamic design of the RC airship, which balances stability and efficiency while maintaining dynamic control for smaller-scale operations.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Preliminary

This chapter summarizes the key conclusions derived from the research and provides insight into potential future directions for further study. The work conducted on the RC airship, focusing on its aerodynamic performance, has contributed significantly to understanding the optimization of lighter-than-air vehicles. Through CFD simulations, the study has demonstrated that design modifications, such as optimized hull shapes and control surface configurations, can effectively enhance aerodynamic performance. The findings emphasize the critical role of innovative design strategies in reducing drag, improving stability, and increasing maneuverability. These advancements highlight the potential for further improving energy efficiency and operational effectiveness in RC airship applications.

5.2 Conclusion

The study successfully explored the aerodynamics of a Remote-Control (RC) Airship, utilizing Computational Fluid Dynamics (CFD) simulations to enhance its design for improved maneuverability, stability, and efficiency. Through a comprehensive analysis of aerodynamic forces, such as lift and drag coefficients, and the impact of body configurations. The research demonstrated the feasibility of designing an optimized RC airship suitable for indoor observation and monitoring applications.

The findings validated the use of streamlined geometries, efficient propulsion systems, and advanced turbulence modeling to achieve low drag and stable lift characteristics. The resulting design achieved a balance between aerodynamic lift and drag, ensuring improved flight performance and controllability. Challenges related to computational limitations and mesh refinement were addressed systematically, contributing to reliable simulation outcomes.

Future work may focus on incorporating advanced turbulence models, leveraging high-performance computing resources, and exploring experimental validation techniques to further refine the aerodynamic design. These enhancements will support the development of more advanced prototypes, extending the applications of RC airships in diverse fields such as surveillance, research, and education.

In conclusion, the project has laid a solid foundation for optimizing RC airship designs through CFD simulations, providing valuable insights for further advancements in the field. The successful completion of this research underscores its contribution to the understanding and innovation of aerodynamics in lighter-than-air vehicles.

5.3 Limitations

The research faced several limitations that impacted the scope and outcomes of the aerodynamic analysis of the RC airship using CFD simulations. One of the primary challenges was the restricted capabilities of the ANSYS Fluent Student version. The software imposed limits on mesh size and solver features, which constrained the resolution and accuracy of simulations. This limitation prevented the use of larger computational grids, leading to approximations in capturing finer aerodynamic details, particularly in areas with high flow gradients. Another limitation was the reliance on simplified flow assumptions. The CFD simulations were conducted under steady-state conditions using basic turbulence models like k-ω SST. These assumptions did not fully represent complex and transient flow phenomena, such as unsteady vortices, turbulence, and flow separation, which are critical for analyzing airship stability and control.

Additionally, gaps in knowledge about airship-specific aerodynamics posed a significant challenge. Limited expertise in the nuances of airship design, such as the interaction between aerodynamic forces and buoyancy or the impact of control surface positioning, affected the ability to optimize the RC airship effectively. Computational constraints further restricted the scope of parametric studies. This limitation hindered deeper exploration of the effects of variables like fin configurations, hull shapes, and propulsion alignments, which are essential for enhancing aerodynamic performance. Lastly, the absence of experimental validation posed a challenge to the reliability of the CFD results. Without real-world benchmarks, such as wind tunnel testing or physical prototypes, the accuracy of the numerical simulations could not be fully verified, adding uncertainty to the findings.

5.4 Recommendations

To overcome the limitations faced in this research, several recommendations are proposed to enhance the effectiveness of CFD simulations for RC airship design. First, transitioning to the professional version of ANSYS Fluent or other high-capability CFD software would eliminate constraints on mesh size and solver capabilities, allowing for more detailed and accurate simulations. Additionally, strengthening knowledge of airship-specific aerodynamics through specialized training or collaboration with experts in lighter-than-air (LTA) vehicle design would improve both the design process and the interpretation of simulation results. This would address the knowledge gaps that limited the ability to optimize configurations effectively.

The adoption of advanced turbulence models, such as Large Eddy Simulation

(LES) or hybrid RANS-LES, is another critical step. These models provide more accurate predictions of transient aerodynamic effects, which are particularly important for understanding high turbulence and flow separation in airship performance. Furthermore, integrating experimental validation into the research process through wind tunnel testing or scaled prototype experiments would provide benchmarks to validate and refine CFD predictions, enhancing their reliability. Expanding computational resources by leveraging high-performance computing (HPC) platforms or cloud-based simulation tools would enable larger, high-fidelity simulations, facilitating a more detailed analysis of complex flow phenomena.

Finally, employing optimization techniques, such as genetic algorithms, gradient-based methods, or machine learning frameworks, would streamline the design process and automate the search for optimal configurations. These methods would allow for faster and more efficient identification of designs that maximize aerodynamic performance and stability. Implementing these recommendations would significantly advance the accuracy and applicability of CFD simulations for RC airship development.

5.5 Challenges

The research faced several challenges that impacted the scope and depth of the analysis conducted using CFD simulations. A significant limitation was the constrained functionality of the ANSYS Fluent Student version, which restricted the resolution and complexity of the simulations. The software's mesh resolution and solver capabilities were insufficient for capturing detailed aerodynamic phenomena, which limited the precision of the results. Furthermore, the lack of access to high-performance computing systems posed another challenge. Without sufficient computational resources, simulation run times were extended, and the ability to perform high-fidelity simulations or conduct extensive parametric studies was severely restricted.

Validation of the CFD results was also a major challenge due to the absence of experimental benchmarks. This lack of real-world data introduced uncertainty in the reliability of the numerical results, particularly for novel configurations that lack established references. The inherent complexity of airship design further added to the challenges. Airships operate under the interplay of buoyant and aerodynamic forces, which require specialized knowledge and advanced tools for precise analysis. This complexity makes airship design more intricate than that of conventional aircraft.

Another significant challenge was accurately capturing transient and unsteady aerodynamic effects, such as wake interactions and flow separation. These phenomena are critical for understanding the stability and control of the airship but are computationally expensive and difficult to model accurately. Finally, limited experience with advanced CFD techniques and turbulence modeling hindered the exploration of intricate aerodynamic behaviors. These knowledge gaps, combined with the computational and software constraints, underscored the need for future improvements and advanced methodologies to fully address the challenges associated with RC airship design and analysis.

5.6 Future Improvements

To enhance the future development and analysis of RC airships, several improvements are recommended. One critical area is the integration of experimental testing with computational studies. Constructing and testing small-scale physical prototypes would validate simulation results and provide a deeper understanding of airship performance under real-world conditions, thereby enhancing the accuracy and reliability of CFD analyses. Additionally, the adoption of higher-fidelity models using the full suite of features available in professional-grade CFD software is essential. These models should include detailed boundary conditions, unsteady flow analyses, and fluid-structure interaction (FSI) modeling to enable a more comprehensive evaluation of aerodynamic performance.

Expanding the scope of simulations to incorporate realistic environmental effects, such as crosswinds, turbulence, and temperature gradients, is another vital improvement. This would provide critical insights into the operational stability of airships under varying conditions. Detailed parametric studies should also be conducted to optimize key design elements, including fin positioning, hull shapes, and propulsion alignment, to maximize aerodynamic efficiency and control. Moreover, the incorporation of autonomous navigation systems in future designs would greatly enhance maneuverability and operational efficiency, particularly for indoor applications where RC airships are frequently deployed.

Finally, advanced post-processing tools should be leveraged to extract detailed insights into aerodynamic phenomena. These tools would facilitate a better understanding of vorticity fields, wake interactions, and pressure distributions, contributing to more effective design improvements. By implementing these advancements, future research can overcome current challenges and significantly enhance the performance, stability, and versatility of RC airships.

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Appendices

APPENDIX A GANTT CHART: PSM 1

Gantt Chhart For PSM 1																
No	Task Project	Status	Week													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Supervisor Selection and Registered PSM Tittle	Plan														
		Actual														
2	Briefing for Project	Plan														
		Actual														
3	Briefing of Chapter 1 (Introduction) with supervisor	Plan														
		Actual								M						
4	Write of Chapter 1 (Introduction)	Plan								I						
		Actual								D						
5	Discussion of Chapter 1(Introduction)	Plan								S						
		Actual								E						
6	Submission of Chapter 1 (Introduction)	Plan								M						
		Actual														
7	Briefing of Chapter 2 (Literature Review) with supervisor	Plan														
		Actual								B						
8	Write of Chapter 2 (Literature Review)	Plan								R						
		Actual								E						
9	Discussion of Chapter 2 (Literature Review)	Plan								A						
		Actual								K						
10	Submission of Chapter 2 (Literature Review)	Plan														
		Actual														
11	Briefing of Chapter 3 (Methodology) with supervisor	Plan														
		Actual														
12	Write of Chapter 3 (Methodology)	Plan														
		Actual														
13	Discussion of Chapter 3 (Methodology)	Plan														
		Actual														
14	Submission of Chapter 3 (Methodology)	Plan														
		Actual														
15	Writing Chapter 4, expected outcome and conclusion	Actual														
		Actual														

APPENDIX B GANTT CHART: PSM 2

Gantt Chhart For PSM 2																
No	Task Project	Status	Week													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Briefing planning of PSM 2	Plan														
		Actual														
2	Geometry setup in Ansys Fluent	Plan														
		Actual								M						
3	Run Meshing for Blimps	Plan								I						
		Actual								D						
4	Modified set up in Mesh	Plan								S						
		Actual								E						
5	Report Writing Chapter 4	Plan								M						
		Actual														
6	Analysis and simulation on Blimps	Plan														
		Actual								B						
7	Analysis and simulation on RC Airship	Plan								R						
		Actual								E						
8	Report Writing Chapter 5	Plan								A						
		Actual								K						
9	Finalize PSM 2 Report	Plan														
		Actual														
10	Submission of PSM 2 Report	Plan														
		Actual														
11	PSM 2 Presentation	Plan														
		Actual														

APPENDIX C

$$F_b = \rho \cdot V \cdot g \text{ (Buoyant Force) (1)}$$

$$C_l = \frac{L}{0.5 \cdot \rho \cdot v^2 \cdot A} \text{ (Aerodynamic Lift Coefficient) (2)}$$

$$C_d = \frac{D}{0.5 \cdot \rho \cdot V^2 \cdot A} \text{ (Drag Coefficient) (3)}$$

$$C_p = \frac{p - p_\infty}{0.5 \cdot \rho \cdot v^2} \text{ (Pressure Coefficient) (4)}$$

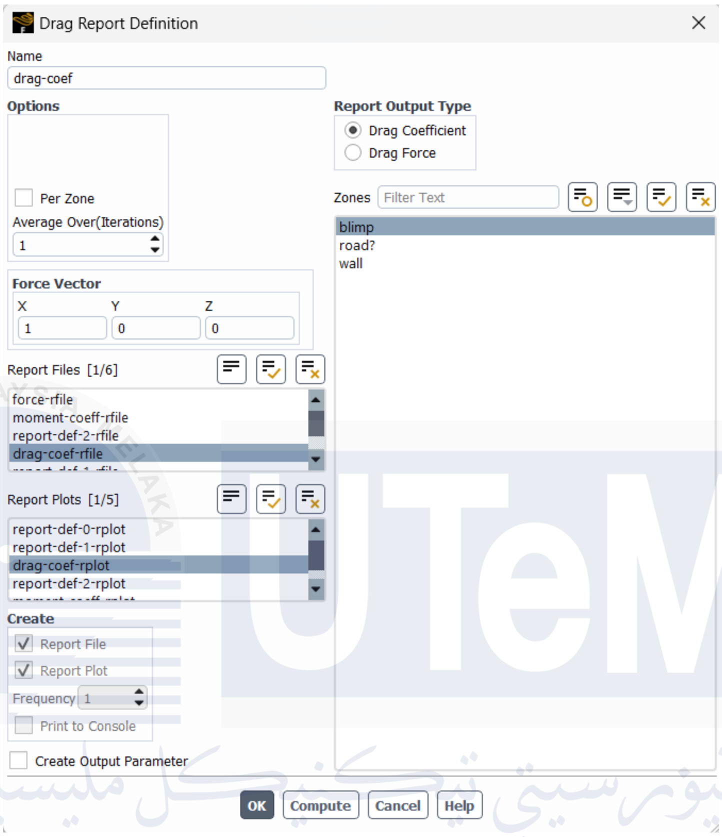
$$C_m = \frac{M}{0.5 \cdot \rho \cdot v^2 \cdot A \cdot l} \text{ (Moment Coefficient) (5)}$$

$$\frac{L}{D} = \frac{C_l}{C_d} \text{ (Lift to Drag Ratio) (6)}$$

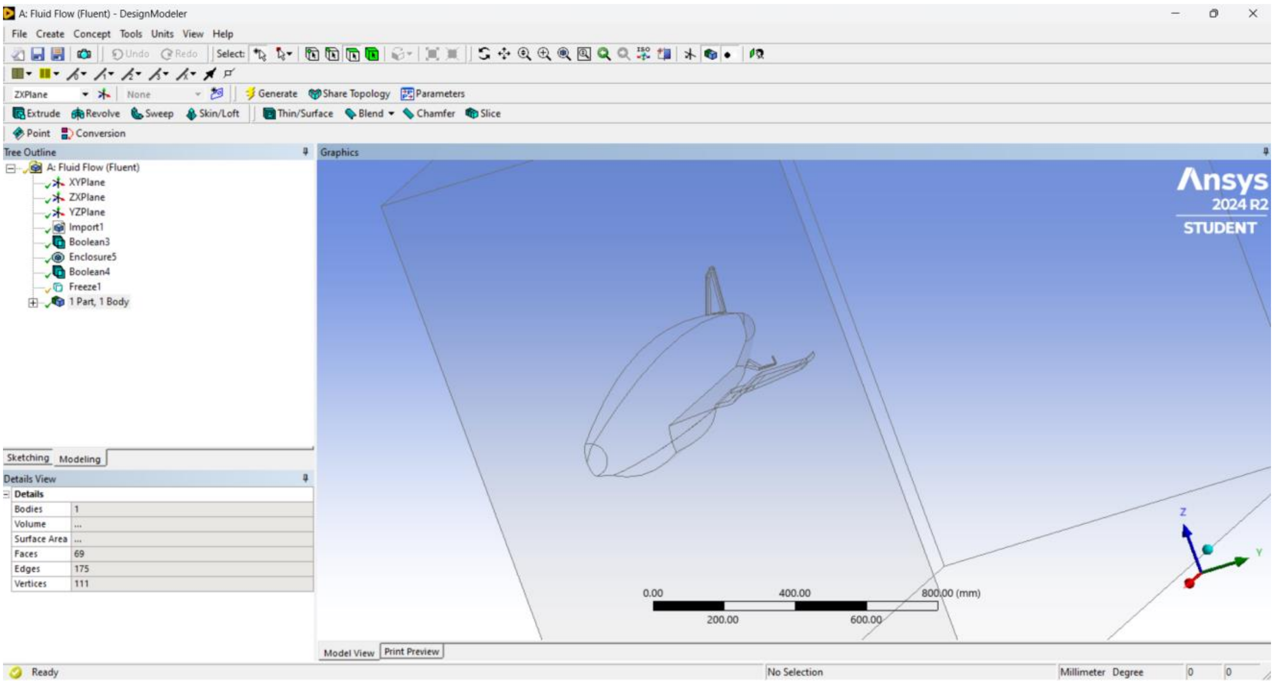
$$Re = \frac{\rho \cdot v \cdot L}{\mu} \text{ (Reynold Number) (7)}$$

APPENDIX D

Solver setting in Ansys Fluent

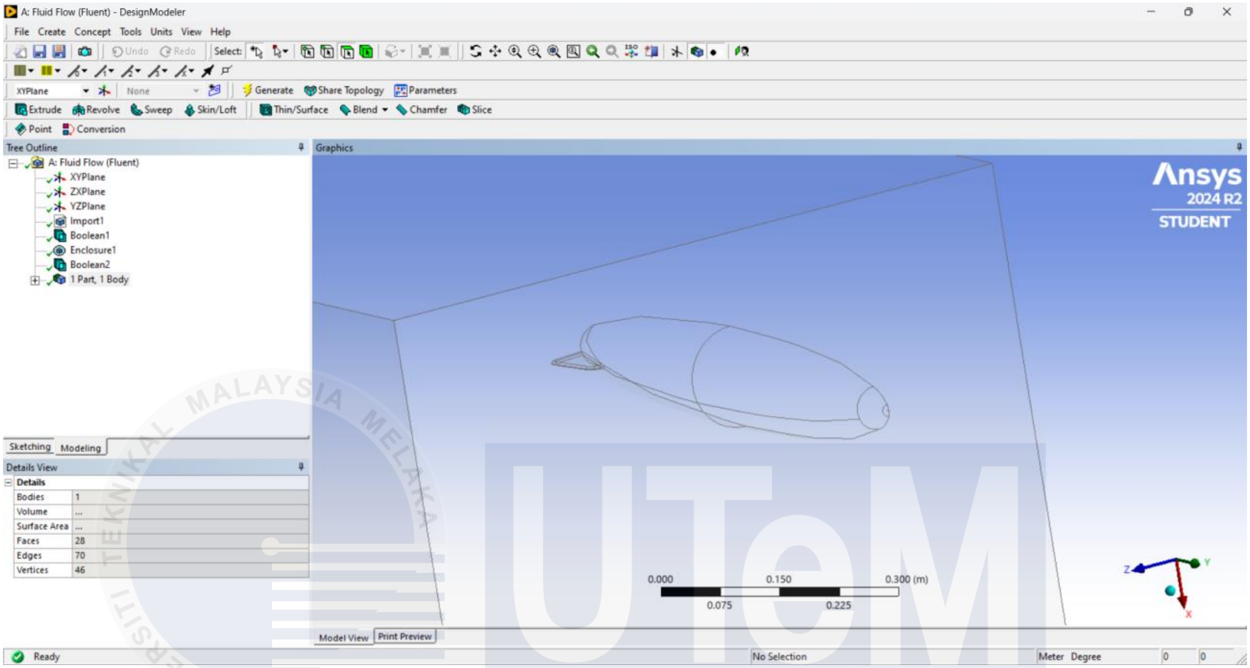


Geometry Adjustment for RC Airship



APPENDIX E

Geometry Adjustment for Blimps



Scaled Residual