A COMPREHENSIVE STUDY ANALYZING THE STRENGTH AND ERGONOMICS OF BICYCLES

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This report is submitted
in fulfillment of the requirement for the degree of
Bachelor of Mechanical Engineering

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DECLARATION

I declare that this project report entitled "A Comprehensive Study Analyzing The Strength And Ergonomics Of Bicycle" is the result of my own work except as cited in the references

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APPROVAL

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

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DEDICATION

To my beloved mother and father

ABSTRACT

Bicycle design optimization for comfort, safety, and user experience is still a problem, especially for Southeast Asian riders, despite the fact that cycling is an environmentally friendly and effective form of transportation. This study fills this gap by using Finite Element Analysis (FEA) and Rapid Upper Limb Assessment (RULA) to analyse important parameters such as rider ergonomics, bio mechanical efficiency, and structural integrity. A comprehensive examination of the literature determines the problems of current designs with an emphasis on handlebar ergonomics, saddle position, and frame geometry. The methodology proposes an improved bicycle design that is optimized for local conditions by integrating survey findings with simulation-based evaluations. Key findings include a significant reduction in ergonomic risks, as evidenced by improved RULA scores (from 3 to 2), and enhanced structural performance, with maximum stress values reduced by 20% under critical loading conditions.These findings offer up possibilities for safer, more comfortable, and environmentally friendly riding solutions by proving that it is feasible to create bicycles that are specifically suited to Southeast Asian demands.

ABSTRAK

Pengoptimuman reka bentuk basikal untuk keselesaan, keselamatan dan pengalaman pengguna masih menjadi masalah, terutamanya bagi penunggang Asia Tenggara, walaupun pada hakikatnya berbasikal adalah satu bentuk pengangkutan yang mesra alam dan berkesan. Kajian ini mengisi jurang ini dengan menggunakan Analisis Elemen Terhad (FEA) dan Penilaian Anggota Atas Rapid (RULA) untuk menganalisis parameter penting seperti ergonomik penunggang, kecekapan bio mekanikal, dan integriti struktur. Pemeriksaan menyeluruh terhadap literatur menentukan masalah reka bentuk semasa dengan penekanan pada ergonomik palang hendal, kedudukan pelana, dan geometri bingkai. Metodologi ini mencadangkan reka bentuk basikal yang lebih baik yang dioptimumkan untuk keadaan tempatan dengan menyepadukan penemuan tinjauan dengan penilaian berasaskan simulasi. Penemuan utama termasuk pengurangan ketara dalam risiko ergonomik, seperti yang dibuktikan oleh skor RULA yang lebih baik (daripada 3 kepada 2), dan prestasi struktur yang dipertingkatkan, dengan nilai tegasan maksimum dikurangkan sebanyak 20% di bawah keadaan pemuatan kritikal. Penemuan ini menawarkan kemungkinan untuk lebih selamat, lebih penyelesaian tunggangan yang selesa dan mesra alam dengan membuktikan bahawa ia boleh dilaksanakan untuk mencipta basikal yang sesuai secara khusus dengan permintaan Asia Tenggara.

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My sincere appreciation goes out to my supervisor, Dr Mohd Asri Bin Yusuff, for all of their help, advice, and knowledge during this assignment. I also like to thank Universiti Teknikal Malaysia Melaka's Faculty of Mechanical Technology and Engineering for providing the tools and facilities that were required. My sincere gratitude is extended to my family and friends for their constant support and inspiration, as well as to my colleagues for their helpful criticism and encouragement. Without the collective efforts of all those who helped make this work a success, it would not have been possible.

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FEA	Finite Element Analysis
RULA	Rapid Upper Limb Assessment

CHAPTER 1

INTRODUCTION

1.1 Background

Cycling is widely recognised as an eco-friendly and effective form of transportation, with many benefits including better health, reduced of an impact on the environment, and greater mobility. Nonetheless, optimising bicycle design to ensure rider comfort, safety, and overall user experience continues to be the primary objective, especially for road bike riders in Southeast Asia. Within this framework, three parameters—frame size and geometry, saddle position, and handlebar position—stand out as critical aspects that affect bicycle ergonomics. The geometry and size of the frame are crucial for assessing the comfort and posture of the rider when cycling. Proper weight distribution and biomechanical efficiency are ensured by suitable frame dimensions, which lowers the chance of discomfort or injury during long rides. Furthermore, because saddle posture controls body weight distribution and pressure points, it has an important effect on rider comfort and performance. By improving steering control and upper body alignment, handlebar position enhances saddle position and the overall ergonomic connectivity of the bike.

Rapid Upper Limb Assessment (RULA) analysis, an ergonomic evaluation tool that is often used can be modified to measure the musculoskeletal stresses and posture that road bike riders in Malaysia encounter when cycling. RULA analysis can offer important insights into the ergonomic suitability of bicycle designs and highlight areas for improvement to enhance rider comfort and lower the risk of cycling-related injuries by evaluating parameters such frame size and geometry, saddle position, and handlebar position.

The purpose of this report is to thoroughly analyse the concepts, design elements, and engineering characteristics related to ergonomic bicycles specifically suited for Southeast Asian users, given the rising popularity of cycling in the region and the growing demand for bicycles that prioritise comfort and ergonomics. This study aims to find opportunities for optimising bicycle design to meet the specific needs and preferences of Southeast Asian cyclists by integrating finite element analysis, ergonomic studies, and RULA analysis. This will improve the riding experience for cyclists and promote cycling as a fun and sustainable mode of transportation.

1.2 Problem Statement

Especially for Southeast Asian riders, the comfort, riding style, safety, and general user experience of a bicycle are greatly influenced by its design and functionality. For example, the figure 1.1 show the different riding style. Unfortunately, current research frequently falls short of providing a thorough analysis of important components of bicycle design, especially when it comes to rider biomechanics, structural strength, and ergonomic considerations—all of which are essential to riders in the area. Although the structural integrity of bicycle frames has been assessed using finite element analysis (FEA) and rider comfort and biomechanics have been studied through ergonomic studies, there is a lack of thorough research that integrates these findings with ergonomic analysis using tools like Rapid Upper Limb Assessment (RULA) to optimise bicycle design for both performance and user comfort, specifically catered to cyclists' preferences and riding conditions.

For bicycle manufacturers, designers, and and urban planners looking to produce bicycles that accommodate to the specific demands and preferences of Southeast Asian bikers, this information gap presents serious obstacles. Through the integration of finite element analysis for structural evaluation, ergonomic studies for biomechanic analysis and rider comfort, and RULA analysis for ergonomic assessment, this research aims to offer insights into the complex connection between ergonomic design and structural integrity in bicycle engineering, with a focus on Southeast Asian cyclists' preferences and needs. This project aims to reduce the risk of musculoskeletal injuries, detect ergonomic risks, optimise bicycle designs, and improve rider comfort and performance for cyclists in Southeast Asia by integrating these techniques.

Figure 1.1 Different types of riding style

1.3 Objective

1. To evaluate the structural strength of bicycle frames using finite element analysis, specifically tailored to the preferences and riding conditions of cyclists in Southeast Asia.
2. To assess the ergonomic design of bicycles through rider comfort and biomechanical studies, focusing on the unique requirements of cyclists in Southeast Asia.

1.4 Scope of Project

1. Reviewing existing literature and research studies on ergonomic principles and bicycle design, with a specific focus on their applicability to cyclists in Southeast Asia.
2. Analyzing the design features and engineering characteristics of ergonomic bicycles, considering the preferences and riding conditions specific to cyclists in Southeast Asia.
3. Applying RULA analysis to assess the ergonomic suitability of bicycle designs.
4. Identifying opportunities and challenges associated with ergonomic bicycle design and adoption.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Across the world, bicycles are a reliable and effective form of transportation, and in Southeast Asia, their popularity has been increasing as a result of increased development and a growing interest in healthy living. Improving rider comfort, safety, and the overall user experience in the area involves an understanding of the ergonomic aspects, structural integrity, and user preferences related to bicycles. With focus on Southeast Asia, this overview of the literature summarises the body of understanding regarding bicycle ergonomics, structural integrity, and user preferences.

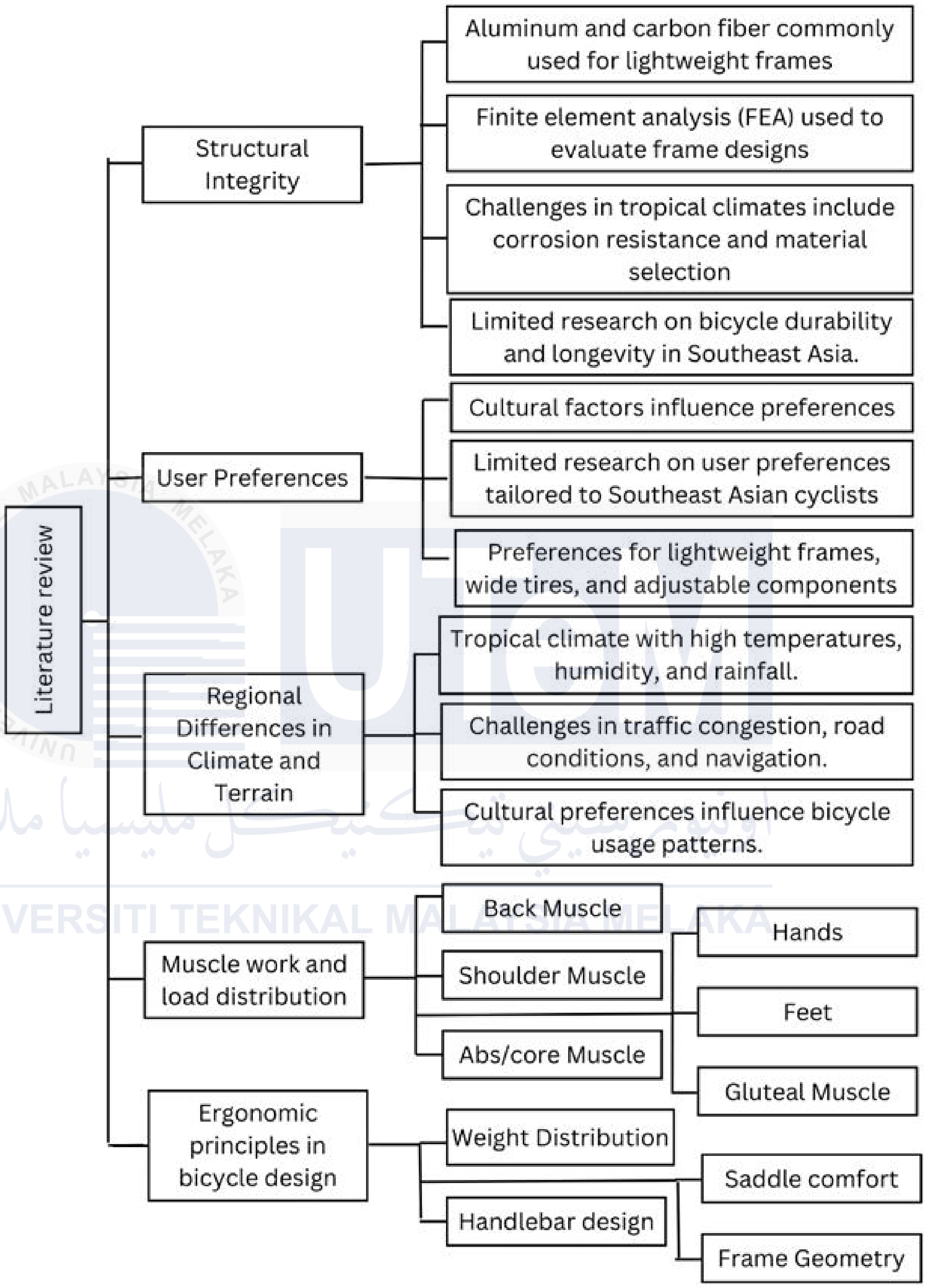


Figure 2.1 Mind map of the literature review

2.2 Road Bike

There is a wide range of bicycles available in the Southeast Asian market, but the focus of this study will be on one of the most popular models: the road bike. A road bike is a specific type of bicycle meant to be used and ridden on smooth, paved surfaces. These bikes are popular for long rides, commuting, racing, and fitness riding because of their design, which focuses speed, efficiency, and mobility. Compared to other bike varieties, they usually have lighter frames, narrow tyres with smooth tread patterns that reduce rolling resistance, drop handlebars that allow for different hand positions, and a more aerodynamic riding posture. Road bikes are available in a variety of types, such as touring bikes shown in figure 2.2 with gear storage, endurance bikes shown in figure 2.3 for longer rides, and racing bikes with speed optimisation. (Merkes et al., 2020)

Figure 2.2 Touring bike

Figure 2.3 Endurance bike

2.3 Structural Integrity

Ensuring the structural integrity of bicycles is essential for rider safety and durability, particularly in diverse terrains and climates found in Southeast Asia. Research on frame materials and construction techniques has focused on improving strength-to-weight ratios and fatigue resistance. For example figure 2.4 below shows fatigue crack in bicycle frame. Aluminum and carbon fiber are commonly used materials due to their lightweight and stiffness properties. Finite element analysis (FEA) has been utilized to evaluate frame designs and optimize structural performance under varying loads and conditions.(Lin et al., 2017)

Figure 2.4 Fatigue crack in bicycle frame

While research on bicycle frame design and materials has primarily been conducted in Western contexts, there is a need for studies that consider the unique environmental and usage conditions in Southeast Asia. Factors such as high humidity, heavy rainfall, and uneven terrain pose challenges to bicycle durability and longevity in the region. Study have explored the impact of environmental factors on bicycle frame materials, highlighting the importance of corrosion resistance and material selection for tropical climates.(Tomaszewski, 2021)

2.4 Finite element analysis

Finite Element Analysis (FEA) plays a critical role in evaluating the structural integrity and performance of bicycle frames. By simulating real-world forces and conditions that act on the frame during riding, FEA provides engineers with invaluable insights into its behavior under stress. This process begins with creating a detailed CAD model of the bicycle frame, including all components and connections. Material properties such as carbon fiber or aluminum are assigned to replicate actual structural characteristics. Engineers then apply boundary conditions that mimic riding scenarios, such as forces, constraints, and loads. The CAD model is meshed into finite elements to facilitate numerical analysis, ensuring accuracy in simulating stress, strain, and deformation as shown in figure2.5 below. Running the FEA simulation allows for the assessment of stress distribution and identification of potential weak points in the frame. Engineers interpret these results to optimize material use, reinforce high-stress areas, and enhance safety and durability. Ultimately, FEA enables iterative improvements in bicycle frame design, ensuring that frames meet rigorous performance standards and deliver optimal riding experiences. (Deepak Hrishikesh & Sara Daniel Jinuchandran Student Assistant Professor, 2021)

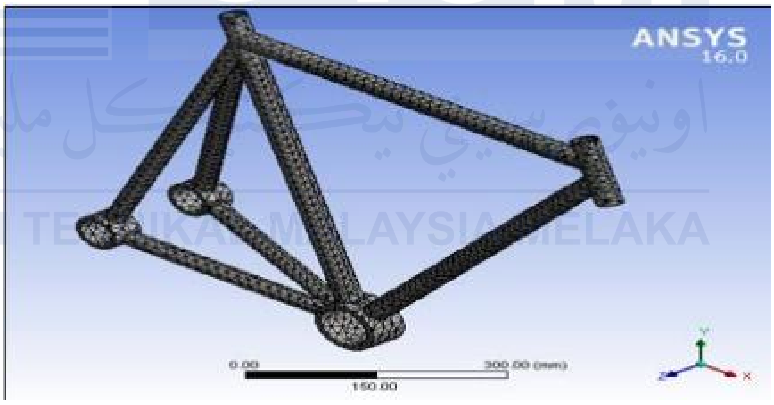


Figure 2.5 Bicycle frame with 5mm meshing

2.5 Rapid Upper Limb Assessment (RULA Analysis)

Rapid Upper Limb Assessment (RULA) is employed within CATIA to assess ergonomic risks related to posture and movement within bicycle design as shown in figure 2.6. This approach leverages CATIA's digital human modeling capabilities to simulate the ergonomic interactions between cyclists and various bicycle components. The process begins with creating virtual prototypes in CATIA, where factors like reach, posture, and joint angles of the cyclist are analyzed. Using RULA assessment criteria, engineers can pinpoint potential ergonomic hazards that may contribute to musculoskeletal stresses. This analysis guides iterative refinements in bicycle design aimed at reducing ergonomic risks and improving rider comfort. By refining designs based on RULA insights, engineers ensure that bicycles promote ergonomic soundness, thereby enhancing overall cycling experiences with a focus on comfort and health (adapted from current knowledge).(Gunturkar, n.d.)

Figure 2.6 RULA score for a riding posture

Table 2.1 Score range of RULA Analysis

Score	Level of MSD Risk
1-2	neglibible risk, no action required
3-4	low risk, change may be needed
5-6	medium risk, further investigation, change soon
6+	very high risk, implement change now

2.6 Factors contributing to discomfort while riding

Several factors contribute to discomfort for cyclists, stemming from both ergonomic design and biomechanical considerations. Ergonomically designed handlebars with proper positioning can alleviate strain on wrists and shoulders, enhancing overall comfort during rides. The design of the saddle, including its width and padding, is crucial to prevent saddle sores and discomfort by ensuring even weight distribution and minimizing pressure points. Additionally, the geometry of the bicycle frame influences riding posture and weight distribution, which can significantly impact comfort, especially over long distances. Biomechanically, improper bike fit or positioning can lead to increased muscle fatigue in the legs and lower back, while poor alignment of pedals or handlebars may strain joints like the knees and wrists, causing discomfort and potential injuries. Addressing these factors through proper bike setup, choosing ergonomically sound components, and maintaining good riding posture is essential to mitigate discomfort and enhance the overall cycling experience (adapted from current knowledge).(Locke, 2006)

2.7 User Preferences

Understanding user preferences is crucial for designing bicycles that meet the needs and expectations of cyclists in Southeast Asia. Research on cycling habits and behaviors in the region has identified a growing interest in urban commuting and recreational cycling, driven by concerns about traffic congestion and environmental sustainability. Figure 2.7 shows the footage of cylcing in Metro Manila. Cyclists in Southeast Asia prioritize comfort, ease of use, and affordability when choosing bicycles, with preferences for lightweight frames, wide tires, and adjustable components. (Ahmed et al., 2024) Cultural factors also influence user preferences, with traditional bicycles and cargo bikes remaining popular choices for transportation and commercial activities in some Southeast Asian countries. the key reasons to choose cycling as a mode of transport relate to personal benefits, for example, lower cost, time savings, higher reliability, greater comfort, ad better personal health. (Bakker et al., 2018)

Figure 2.7 Footage of cycling in Metro Manila

2.8 Regional Differences in Climate and Terrain

The performance and design considerations of bicycles are influenced by the unique climatic and geographical characteristics of different regions around the world. In comparison to other regions, Southeast Asia presents distinct challenges and opportunities for bicycle design and usage. Southeast Asia experiences a tropical climate characterized by high temperatures, humidity, and frequent rainfall throughout the year. These climatic conditions pose challenges for bicycle components and materials, particularly in terms of corrosion resistance and durability. Bicycles used in Southeast Asia may require special coatings or materials to withstand exposure to moisture and humidity, as well as regular maintenance to prevent rust and degradation of components. In contrast, regions with temperate climates, such as Europe and North America, may experience greater temperature variations and seasonal changes. Bicycles designed for these regions may prioritize thermal insulation, weatherproofing, and stability in different weather conditions, including snow, ice, and rain.(Nankervis, 1999)

According to a study by (Bakker et al., 2018) the terrain in Southeast Asia varies widely, ranging from densely populated urban centers to rural villages, mountains, and coastal regions. Urban areas often present challenges such as traffic congestion, narrow streets, and uneven road surfaces, requiring bicycles to be maneuverable, agile, and able to withstand frequent starts and stops. Rural areas may feature rough or unpaved roads, steep gradients, and challenging off-road trails, necessitating bicycles with robust frames, suspension systems, and wider tires for improved traction and stability. Figure 2.8 shows examples of shared paths, bicycle lanes on the road. In contrast, regions with flatter terrain, such as the Netherlands, may prioritize bicycles with lightweight frames, aerodynamic designs, and efficient drivetrains for long-distance commuting and recreational cycling.

Figure 2.8 Examples of shared paths, bicycle lanes on the road

Cultural preferences and infrastructural developments also influence bicycle usage patterns and design preferences in Southeast Asia compared to other regions. In countries like the Netherlands and Denmark, where cycling is deeply ingrained in the culture and supported by extensive cycling infrastructure, bicycles are often designed for comfort, practicality, and ease of use in urban environments. In Southeast Asia, where cycling may serve as a primary mode of transportation for commuting, delivery, and recreational purposes, bicycles may be adapted to carry heavy loads, navigate congested streets, and withstand long hours of use. Cargo bikes, tricycles, and electric bicycles are popular choices in some Southeast Asian countries, offering versatility and efficiency for transporting goods and passengers in urban and rural settings.

2.9 Gaps and Future Directions

While existing research provides valuable insights into bicycle ergonomics, structural integrity, and user preferences, several gaps warrant further investigation. Limited studies specifically address the ergonomic needs of cyclists in Southeast

Asia, and there is a lack of research on the adaptation of existing ergonomic principles to the region's unique cultural and environmental context. Future research should explore innovative design solutions that optimize rider comfort, safety, and performance for cyclists in Southeast Asia, taking into account the diverse usage patterns, terrains, and climatic conditions prevalent in the region (Said et al., 2022)

2.10 Muscle work and load distribution

Every time a person rides a bicycle, every part of their body is engaged as shown in the figure 2.9 below. Many muscles play a role, and each muscle has its opposite. The pedal cycle consists of two main phases: the power phase, which occurs between 12 and 6 o'clock when most of the force is generated to move the bike forward, and the recovery phase, which occurs from 6 to 12 o'clock. Research on ergonomic design principles in bicycles has focused on optimizing rider comfort, performance, and safety. Biomechanical studies have examined the interaction between cyclists and their bicycles, analyzing factors such as posture, joint angles, and muscle activation. For instance, (Turpin & Watier, 2020) used motion capture technology to study the biomechanics of cycling and its implications for bicycle design.

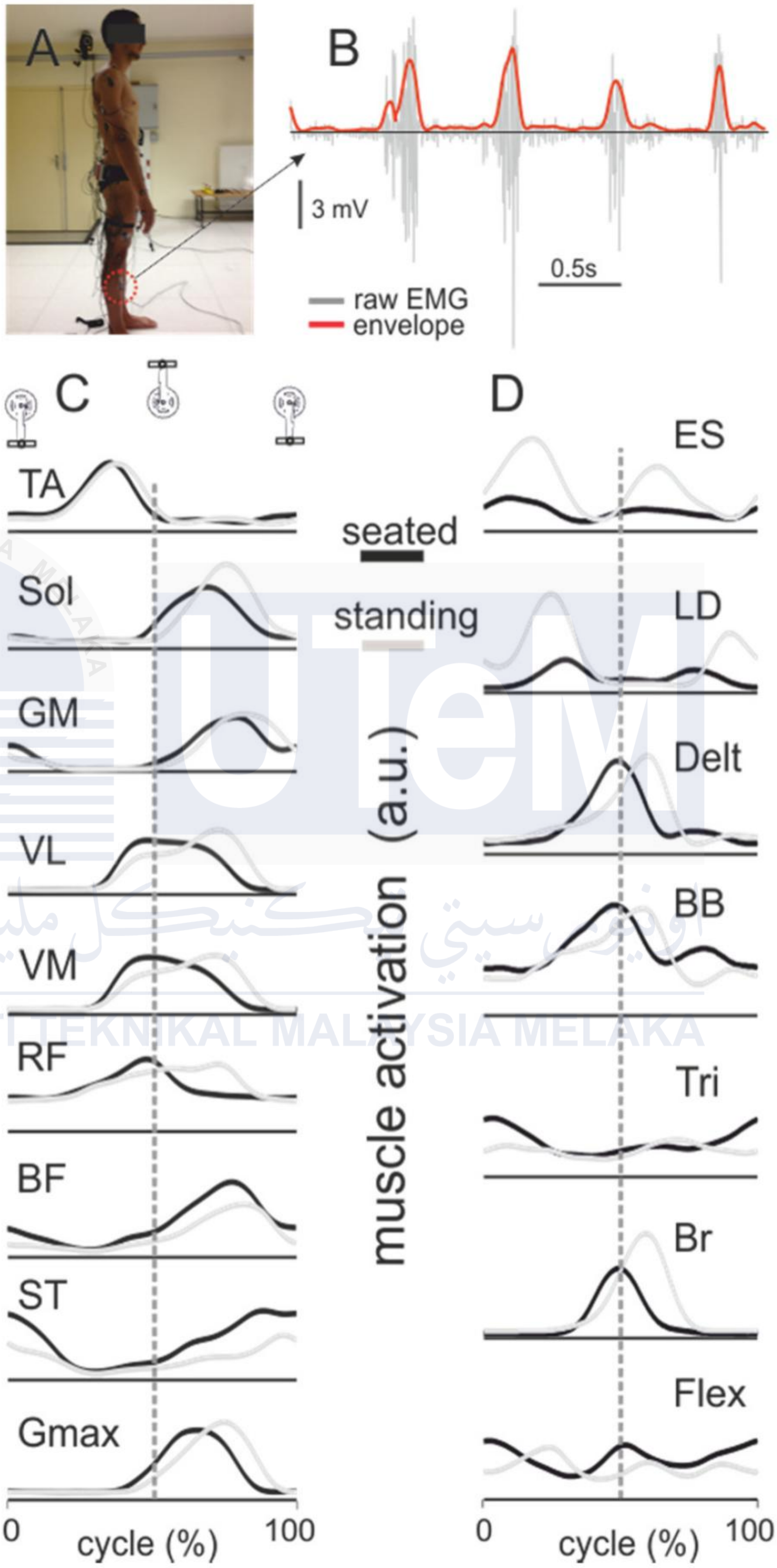


Figure 2.9 Muscle activation during cycling

2.11 Weight distribution

Weight distribution and torque delivery are closely interconnected in bicycle dynamics. The back wheel of a modern bicycle is rotated by a chain or belt moved by the pedals. In most bicycle geometries, the front wheel carries 20–30% of the weight, and the rear wheel carries 70–80%. For instance, a rider weighing 80 kg has a weight distribution where approximately 21% of the weight is on the front wheel and 79% is on the rear wheel. This distribution reflects a person sitting on a bicycle, with the rear wheel, which has traction, experiencing the greater force in most bicycle geometries.

Torque delivery refers to the traction force resulting from torque applied to the wheel's radius. To transfer torque effectively, the traction force must be equal to or less than the force resulting from friction (grip). The torque is produced by pedaling or a motor, causing the wheel and bicycle to move forward. If the traction force exceeds the tire's grip on the road surface, minimal torque delivery occurs. When torque delivery is greater than grip, the tire spins, and the wheel may not move forward effectively (*IJRESM_V2_I5_93*, n.d.)

2.12 Handlebar design

Handlebars are widely recognized as a crucial point of communication between the rider and their bicycle, significantly influencing a rider's comfort and control. However, aerodynamics has recently become a major driver of handlebar innovation, affecting how the rider positions their body through the airflow.

Traditionally, handlebar widths for road racing have been 40 cm or wider following the figure 2.10 below which showing the standard size of road bike handlebar. Riders are typically fitted with handlebars that match their shoulder width to avoid strain through the upper body by aligning the wrists and shoulders. This fitting is particularly important for long-distance events. However, when speed and performance are the top priorities, comfort is occasionally compromised (Malizia & Blocken, 2020)

Figure 2.10 Standard size of road bike handlebar

2.13 Saddle comfort

Road bikes frequently have extremely narrow saddles to minimize resistance and enable maximum leg movement. A fast-riding position on a road bike shifts the rider forward, placing more weight on the hands and feet, and reducing the load on the seat. In contrast, on a cruiser bike with wide backswept handlebars, most of the body weight is placed directly on the seat. Riders on cruiser bikes do not need to pedal quickly. Including the legs biomechanics as well as in the figure 2.11 below. These factors make a wide, heavily padded saddle ideal for supporting body weight and providing cushioning (Giubilato & Petrone, 2014)

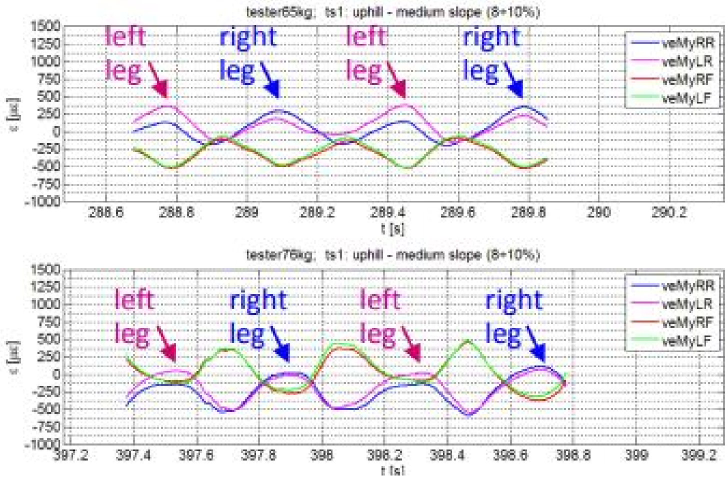


Figure 2.11 Biomechanics study of a saddle

2.14 Frame geometry

The angles and measurements between the main components of a bike frame, such as the head tube, fork, seat and chain stays, down tube, and top tube, define the frame's geometry shown in figure 2.12 below with labels. The geometry of the frame depends on its intended use, which dictates its design. For example, a road bicycle has handlebars positioned further apart and lower compared to the saddle, resulting in a more hunched riding position. In contrast, a hybrid bicycle prioritizes comfort with handlebars that are higher, creating an upright riding position (Regenwetter et al., 2022)

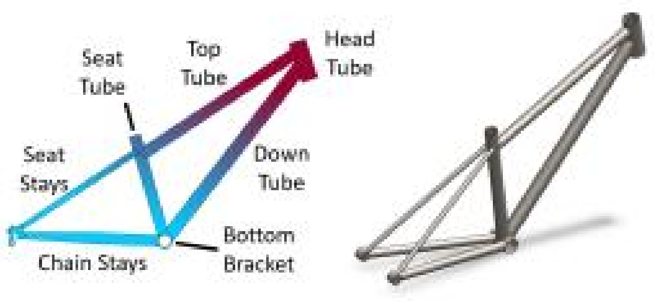


Figure 2.12 Frame geometry of a road bike

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter outlines the research methodology employed in this study, detailing the processes involved in data collection, analysis, and interpretation to achieve the objectives outlined in Chapter 1. The methodology integrates finite element analysis (FEA), ergonomic studies, and Rapid Upper Limb Assessment (RULA) analysis to comprehensively assess and optimize bicycle design specifically for Southeast Asian cyclists. FEA is utilized to evaluate the structural integrity and performance of bicycle frames under various conditions, while ergonomic studies focus on rider comfort and biomechanical efficiency. RULA analysis assesses ergonomic risks associated with posture and movement, providing insights into potential improvements in design to enhance overall comfort and safety. Together, these methodologies ensure a holistic approach to understanding and improving bicycle design tailored to the unique needs of cyclists in Southeast Asia.

3.2 Identifying customer needs

An online survey using a Google Form was used to gather information about client wants. The survey's purpose was to gather comprehensive data on the ergonomic preferences, structural requirements, and cycling habits of Southeast Asian cyclists. 53 people in total responded to the survey after it was distributed to possible responders. The survey could be accessed by visiting https://docs.google.com/forms/d/e/1FAIpQLSfv1TMD3R51pssOA2Xld5m6BIqYWO7ZylzeOakCD5n3wnEKfA/viewform?usp=sf_link. (Sui Jing Xian, 2024)The survey's goal was to gather data on riding habits and ergonomic challenges. Observational studies will complement survey data by analyzing riders' postures during cycling. Sixteen questions made up the survey questionnaire, covering a range of topics including age, gender, height, weight, cycling habits, bike setup and ergonomics, bike performance and strength. The survey results, which are represented in Figure 3.1 to Figure 3.16, gave important insights into the ergonomic and structural preferences and challenges faced by the target users with regard to bicycle strength and ergonomic. These data feature pie charts that show the distribution of answers for each question, giving the survey results a visual representation.

3.3 Design Parameters

Questions that provide insights into users' preferences, experiences, and expectations are selected for the survey to translate the responses into customer requirements and engineering characteristics. This involves mapping specific survey questions to the engineering characteristics that correspond to the identified customer requirements. This approach ensures that the survey effectively captures relevant data, which can then be used to inform the design and development process, aligning product features with user needs and expectations.

3.3.1 Customer requirements and Engineering Characteristics

Section 2: Cycling Habits

1. How often do you ride your bike?

Customer Requirement: Frequency of use

Engineering Characteristic: Durability and maintenance schedule

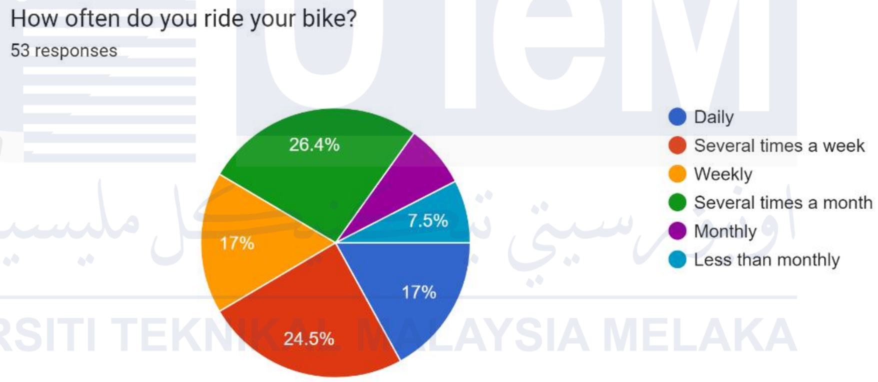


Figure 3.1 Frequency of use

2. What type of terrain do you usually ride on?

Customer Requirement: Suitability for different terrains

Engineering Characteristic: Suspension system, tire grip, frame geometry

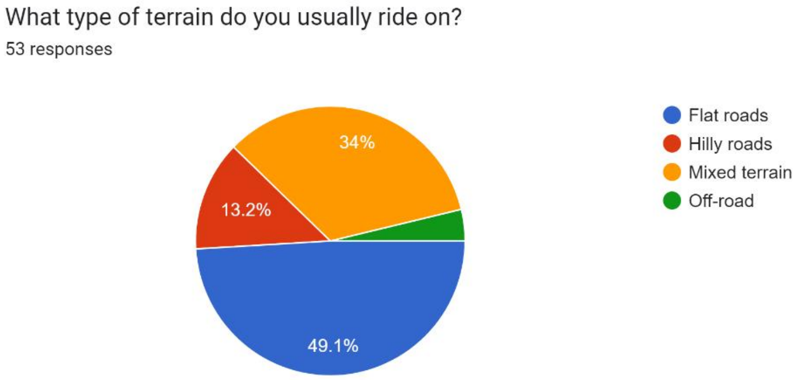


Figure 3.2 Suitability for different terrains

3. What is the average duration of your rides?

Customer Requirement: Comfort over long periods

Engineering Characteristic: Saddle design, handlebar ergonomics, vibration dampingtomer requirements

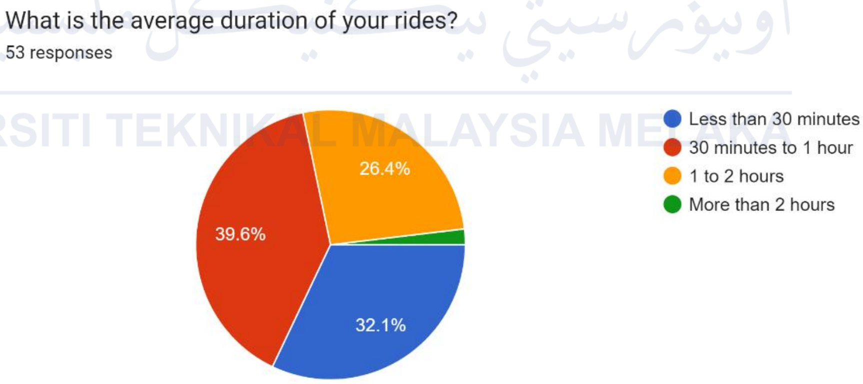


Figure 3.3 Comfort over long periods

Section 3: Bike Setup and Ergonomics

4. How did you determine your bike fit?

Customer Requirement: Accessibility to proper bike fitting

Engineering Characteristic: Adjustable components (seat post, handlebars, stem)

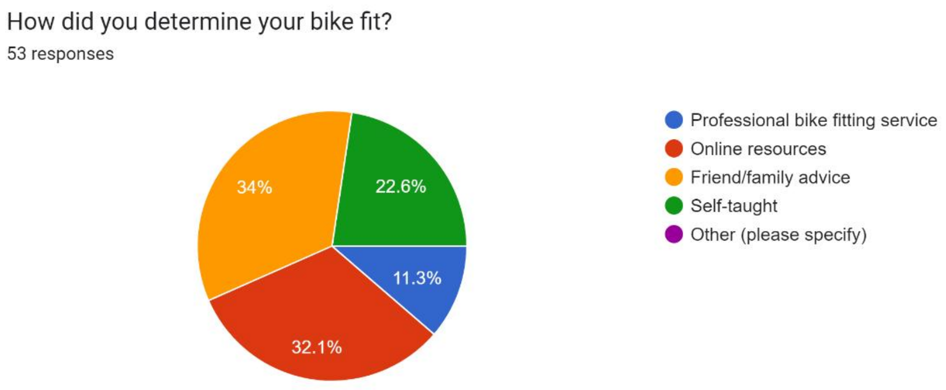


Figure 3.4 Accessibility to proper bike fitting

5. Do you experience discomfort or pain while riding? (Check all that apply)

Customer Requirement: Comfort and injury prevention

Engineering Characteristic: Ergonomic design, material choice, frame geometry

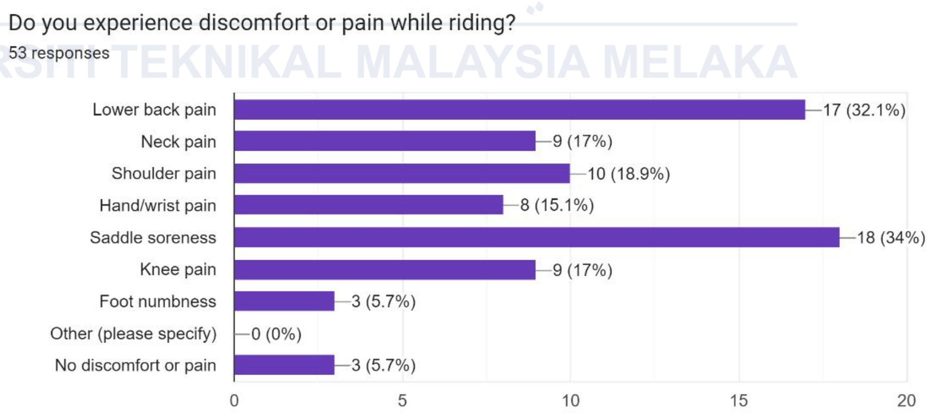


Figure 3.5 Comfort and injury prevention

6. On a scale of 1 to 5, how would you rate the overall comfort of your bike setup?

Customer Requirement: Overall comfort

Engineering Characteristic: Ergonomic design, adjustability

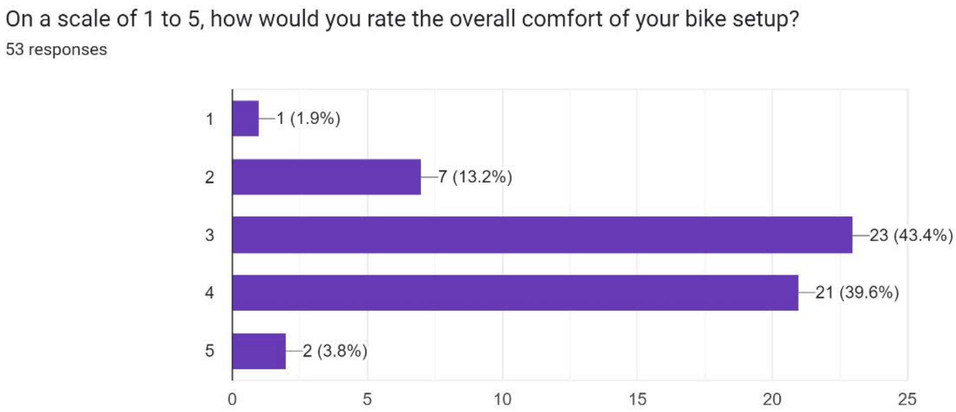


Figure 3.6 Overall comfort

Section 4: Bike Performance and Strength

7. What material is your bike frame made of?

Customer Requirement: Preference for specific materials

Engineering Characteristic: Material properties (weight, strength, stiffness)

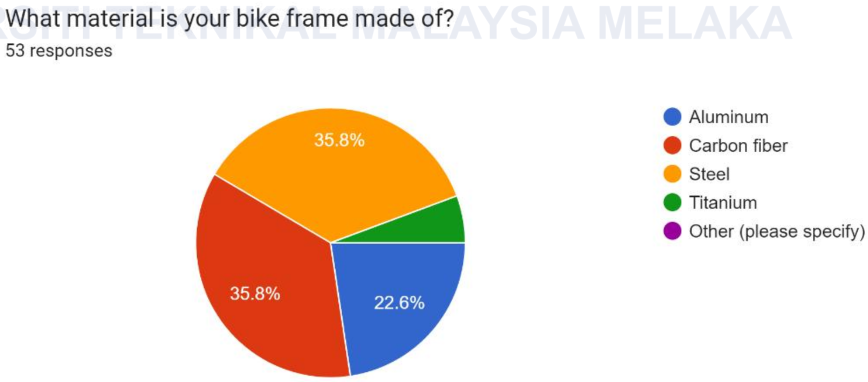


Figure 3.7 Preference for specific materials

8. Have you ever experienced any structural issues with your bike frame or components?

Customer Requirement: Reliability and safety

Engineering Characteristic: Structural integrity, fatigue resistance

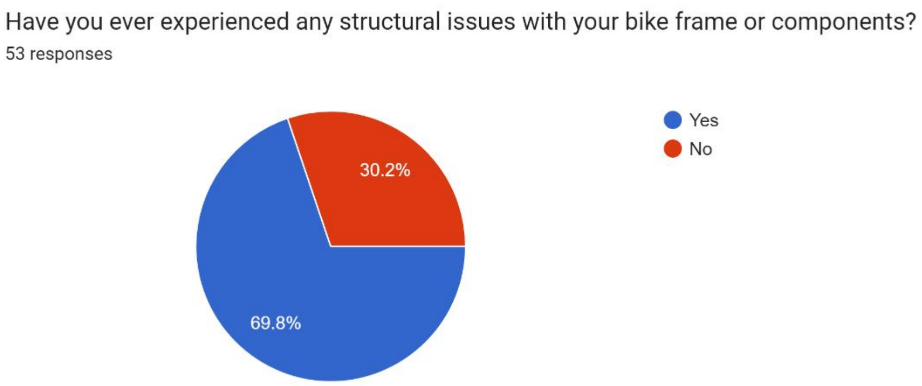


Figure 3.8 Reliability and safety

9. On a scale of 1 to 5, how would you rate the durability of your bike?

Customer Requirement: Durability

Engineering Characteristic: Material properties, manufacturing quality

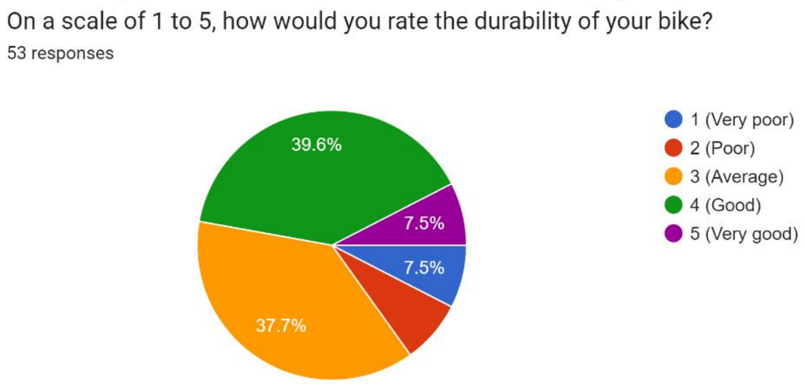


Figure 3.9 Durability

Table 3.1 Customer requirements and engineering characteristics

Customer requirements	Engineering characteristics
Frequency of use	Durability and maintenance schedule
Suitability for different terrains	frame geometry
Comfort over long periods	Saddle design ergonomics
Accessibility to proper bike fitting	adjustable features and foldable or collapsible handlebars
Durability	Material properties
Reliability and safety	Structural integrity, fatigue resistance

3.3.2 Benchmarking

To compare the performance and ergonomic features of existing road bike designs with the new designs proposed in this study, three leading road bike models were selected for benchmarking, representing different segments in the market:

- High-end Segment: Tarmac SL8 Expert
- Mid-range Segment: SuperSix EVO 4
- Entry-level Segment: RC520 Disc Road Bike – 105

This comparison will provide a comprehensive evaluation of how the new designs stack up against established models across various market segments, highlighting potential improvements and areas for further development in table 3.2 below.

Table 3.2 Benchmarking

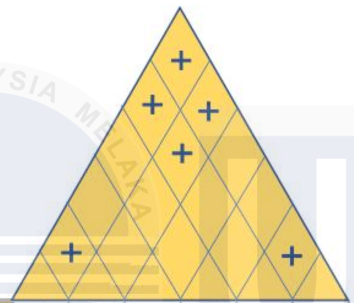
Criteria	 **Tarmac SL8 Expert**	 **RC520 Disc Road Bike - 105**	 **SuperSix EVO 4**
Frame Material	Carbon Fiber	Aluminum	Carbon Fiber
Frame Geometry	Racing Geometry	Endurance Geometry	Racing Geometry
Weight	7.0 kg	9.5 kg	7.8 kg
Stress Analysis	Max Stress: 125 MPa	Max Stress: 160 MPa	Max Stress: 135 MPa
Handlebar Design	Aero Bars	Drop Bars	Drop Bars
Saddle Design	Gel-padded Racing Saddle	Standard Saddle	Ergonomic Racing Saddle
Drivetrain Components	Shimano Ultegra	Shimano 105	SRAM Force AXS

Criteria	 Tarmac SL8 Expert	 RC520 Disc Road Bike - 105	 SuperSix EVO 4
Braking System	Disc Brakes	Disc Brakes	Disc Brakes
Wheelset	Aero Carbon Wheels	Standard Aluminum Wheels	Aero Carbon Wheels
Rider Reviews	4.9/5	4.3/5	4.7/5
Comfort	High	Moderate	High
Handling and Stability	Excellent	Good	Very Good
Durability	High	Moderate	High
Ease of Maintenance	Moderate	Easy	Moderate
Cost	$5500	$1500	$4000

3.4 Quality function deployment

3.4.1 House of Quality

The House of Quality (HOQ) matrix in figure 3.10 was constructed to visualize and analyze the relationships between customer requirements and engineering characteristics. This ensures that the design process aligns with the needs and preferences of the target market. By mapping customer needs to specific engineering attributes, the HOQ matrix helps prioritize design features, facilitating a systematic approach to product development that ensures the final design meets user expectations and industry standards.



Minimize or Maximize			↑	●	↑	●	●	↑				
House Of Quality			Engineering Characteristics (How							Competitive Assessment		
			Durability and robustness	Frame geometry	Saddle design ergonomics	Adjustable features handlebars	Material properties	Structural integrity, fatigue resist				
Customer Requirements (What)		**Importance**	1	2	3	4	5	6	Weighted Score	nac SL8 Ex	RC520	SuperSix EVO
1	Frequency of use	9			9	81		9	99	4	3	5
2	Suitability for different terrains	6	54	18		6	6	18	102	5	4	4
3	Comfort over long periods	7		63	63	63			189	3	5	3
4	Accessibility to proper bike fitting	8		24	72	24			120	5	4	5
5	Durability	8	72	24			72	24	192	5	3	5
6	Reliability and safety	7	21	7			21	21	70	4	4	4
		Importance	147	136	144	174	99	72	772			
		Importance %	19	17.6	18.7	22.5	12.8	9.33	100			

Correlations:
++ Strong Positive
+ Positive
- - Strong Negative
- Negative

Relationships:
Strong= 9
Medium= 3
Weak= 1

Figure 3.10 House of Quality

3.4.2 Key Engineering Characteristics

Table 3.3 shows the key engineering characteristics that is highlighted by the customer based on the survey conducted that is needed in the bike.

Customer requirements	Remark
Frequency of use	Bike should withstand frequent use and last long.
Suitability for different terrains	Bike should perform well on various types of terrain.
Comfort over long periods	Bike should reduce discomfort and prevent pain
Accessibility to proper bike fitting	Easy access to professional bike fitting services.
Durability	Bike should have a long lifespan and resist wear. Preference for certain materials in bike construction.
Reliability and safety	Bike should be reliable and safe to ride.

3.4.3 List of Decision Characteristics

Table 3.4 shows the list of decision characteristics based on the bike that will be built. It shows what is needed for the bike to ensure that customer requirements are fulfilled.

Engineering Characteristic	Remark
Durability and robustness	Components and materials should be selected for their ability to withstand repeated stress and use.
Frame geometry	Frame design should be optimized for stability, handling, and comfort, considering various riding conditions.
Saddle design ergonomics	Saddle should be ergonomically designed to provide comfort and support over long rides, minimizing discomfort.
Adjustable features and foldable or collapsible handlebars	Handlebars should be adjustable to accommodate different riding styles and preferences, with optional foldable or collapsible features for portability.
Material properties	Selection of materials should consider factors like weight, strength, stiffness, and corrosion resistance.
Structural integrity, fatigue resistance	Bike frame and components should be engineered to maintain structural integrity and resist fatigue under repeated stress and use.

3.5 Morphological Chart

Table 3.5 Morphological Chart

Parameter	Option 1	Option 2	Option 3	Option 4
Frame Material	Carbon Fiber	Aluminum	Steel	Titanium
Frame Geometry	F shape Geometry	Single triangle Geometry	X shape Geometry	C shape geometry
Handlebar Design	Angled butterfly bars	Front lift handlebar with elbow support	Flat elbow support bar	Bullhorn Bars
Saddle Design	Gel-padded Racing Saddle	Anatomical with hip support	Anatomical with lumbar support	Central cut put saddle

3.6 Concept evaluation

3.6.1 Design concept 1

The bicycle design drawn in figure 3.11 emphasizes several ergonomic features to enhance rider comfort and performance. The anatomical saddle is crafted with hip support to ensure comfort during long rides. The angled butterfly handlebar offers multiple grip positions, reducing strain on the rider’s hands and wrists. Additionally, the F-shape lightweight frame geometry contributes to the bicycle's overall lightness and potentially improves aerodynamic efficiency.

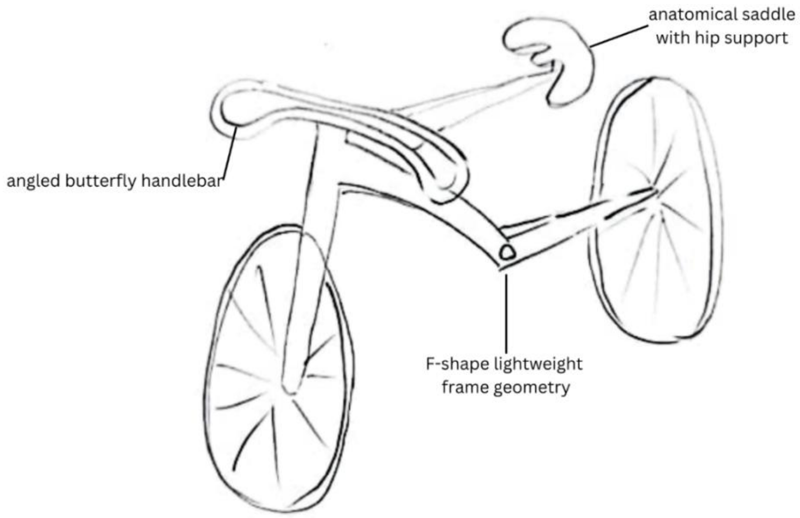


Figure 3.11 Design concept 1

3.6.2 Design concept 2

The design drawn in figure 3.12 with anatomical saddle is designed with lumbar support to enhance rider comfort. The bike's frame follows a single triangle geometry, contributing to its structural integrity. Additionally, the front lift handlebar features elbow support, improving rider stability. This design emphasizes both functionality and comfort.

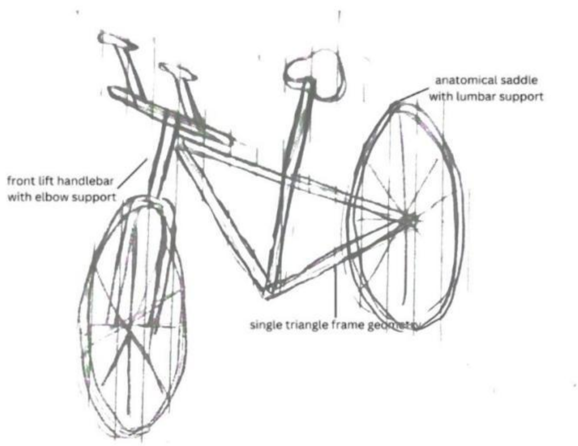


Figure 3.12 Design concept 2

3.6.3 Design concept 3

The drawing of the bicycle in figure 3.13 highlights its design for comfort and aerodynamics, featuring several key elements. The central cut-out saddle is designed to reduce pressure on the rider's body, enhancing comfort during long rides. The elbow support handlebar provides support for the rider's elbows, allowing for a relaxed arm position. Additionally, the X-shape frame geometry offers a unique structural design that likely contributes to both the bike's ergonomic feel and overall strength. These features ensure that the bicycle is both comfortable and efficient for long-distance riding.

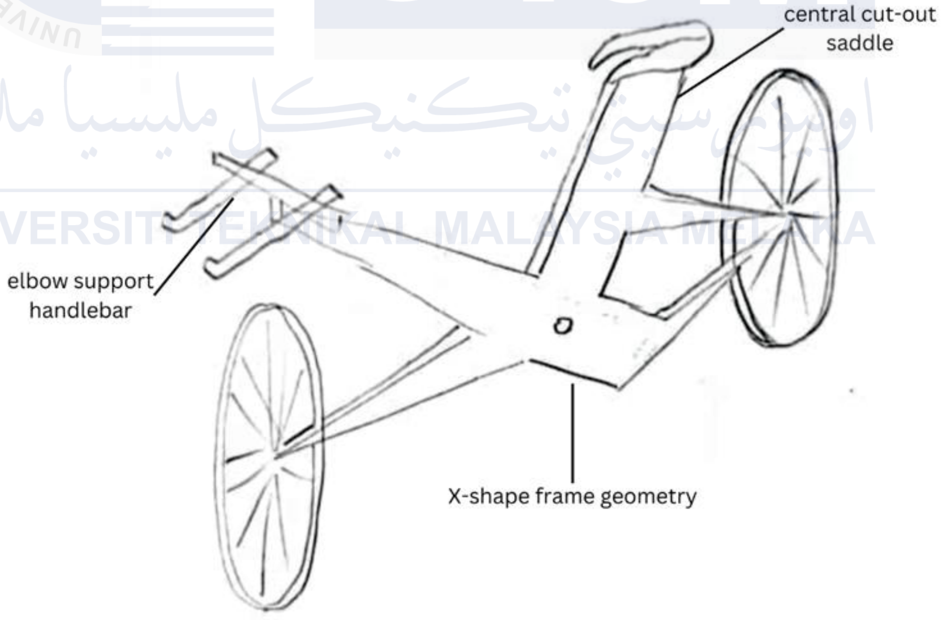


Figure 3.13 Design concept 3

Table 3-6 displays the weightage scheme for the criteria, categorizing functions by weighting the requirements for the project's functions and ranking their importance from 1 to 5 and the rating scheme for scoring the concept design. Based on the design and functionality of the design according to the criteria of the bike, the rating will be assigned by inspecting the requirements. The Pugh chart in Table 3-7 presents the results of the concept design based on the requirements for the bike. According to the total ratings given by the concept design requirements, concept design 2 receives the highest score compared to designs 1 and 3. Each design has unique standards applicable to the overall project design. However, concept design 2 received the best score as it met the most critical requirements of the project concept, leading to a higher overall grade.

Table 3.6 The rating and weightage for the criteria

Criteria	**Weight**	**Concept A**	**Concept B**	**Concept C**
Comfortable Handlebar	4	3	4	2
Lightweight Design	3	4	3	5
Portability	3	5	3	4
Ease of Control	5	4	5	3
Comfortable Suspension	4	3	4	5
Robust Frame Material	4	4	4	3
Aerodynamic Design	3	5	4	3
Adjustable Features	3	3	5	4

Table 3.7 Pugh Chart

Criteria	Weight	Concept A	Concept B	Concept C
Comfortable Handlebar	4	12	16	8
Lightweight Design	3	12	9	15
Portability	3	15	9	12
Ease of Control	5	20	25	15
Comfortable Suspension	4	12	16	20
Robust Frame Material	4	16	16	12
Aerodynamic Design	3	15	12	9
Adjustable Features	3	9	15	12
Total Score		111	118	103

3.7 Embodiment design

Product architecture, configuration design, and parametric design are the three activities comprising the Embodiment Design process. The product architecture involves the arrangement of physical components, where a collection of these components is known as modularity. Configuration design consists of the preliminary selection of materials and manufacturing processes, along with the modeling and sizing of parts. Parametric design is robust, focusing on significant tolerances, exact values, and dimensions that are deemed to be of high quality.

3.7.1 Product architecture

The product architecture mapped in figure 3.14 defines the overall layout and structure of the road bike, breaking it down into major subsystems and components. This systematic arrangement includes the frame, handlebars, saddle, wheels, drivetrain, and braking system, ensuring each part functions cohesively to enhance the bike's performance and meet design objectives.

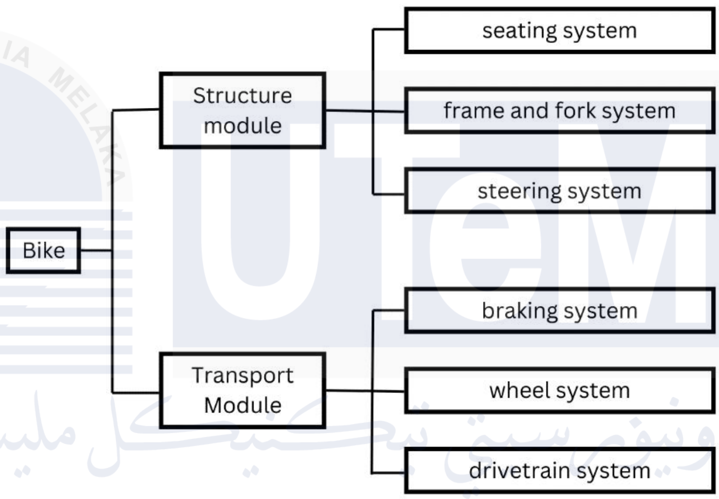


Figure 3.14 Product architecture of a bicycle

Frame and Fork System:

- Frame
- Fork

Steering System:

- Handlebars
- Stem
- Headset

Seating System:

- Saddle
- Seat post

3.7.2 Configuration design

Configuration design involves organizing these subsystems and components to establish the comprehensive product structure and specify how they interact. This process ensures that each element within the road bike, such as the frame, handlebars, saddle, wheels, drivetrain, and braking system, is integrated harmoniously. By carefully configuring these parts, designers optimize functionality, performance, and user experience, aligning with the intended design objectives and ensuring efficient assembly and operation of the bicycle.

Frame and Fork System:

- **Frame:** Aluminum for Lightweight and affordable, with good stiffness.
- **Fork:** Aluminium fork for shock absorption and lightweight.
    - Width: 25mm for a balance between speed and comfort.

Steering System:

- **Handlebars:**
    - Material: Aluminium alloy for vibration damping.
    - Shape: Elbow support bar for ergonomic positioning.

Seating System:

- **Saddle:**

- Shape: Anatomically designed for road cycling with lower back rest
- Material: Carbon fiber with memory foam padded

- **Seat Post:**
  - Material: Aluminium alloy for vibration damping.
  - Diameter: 27.2mm standard.

3.7.3 Parametric Design

Frame Geometry:

- **Top Tube Length:** Adjustable between 520mm and 580mm in increments of 10mm to accommodate different rider sizes.
- **Head Tube Length:** Adjustable from 120mm to 215mm to fit different rider heights and preferences.

Handlebar Width and Lift:

- **Width:** 400mm suit different rider shoulder widths.
- **Lift:** Adjustable from 125mm to 150mm to fit different riding styles and preferences.

Seating System

- **Saddle Shape and Dimensions:**
  - Parameters: memory foam padded
  - Usage: Optimizing for rider comfort and pedaling efficiency.
- **Seat Post Length:**
  - Length : Adjustable for rider height and preferred riding position.

3.7.4 Technical Drawing

Technical drawing of every element in figure 3.15, 3.16, 3.17, 3.18, 3.19, 3.20 specifies the precise dimensions, materials, and manufacturing processes for each component and subsystem of the road bike. For the clearer drawing (see Appendix A, Appendix B, Appendix C) Technical drawings play a critical role in engineering and manufacturing by specifying the exact geometric dimensions, tolerances, material specifications, and surface finishes required for each component of the product. These drawings provide detailed instructions to ensure consistency and precision during production. Geometric dimensions define the size and shape of each part, while tolerances establish permissible variations to ensure parts fit together correctly. Material specifications outline the type of material, such as aluminum or carbon fiber, with specific properties like strength and weight. Surface finishes detail the texture or treatment applied to achieve desired aesthetics or functional characteristics. Together, technical drawings serve as essential blueprints that guide manufacturers in producing components that meet design requirements and quality standards efficiently.Engineers and designers determine exact measurements, select appropriate materials based on strength, weight, and durability requirements.

Frame and Fork System:

Figure 3.15 CAD model of the frame and fork system

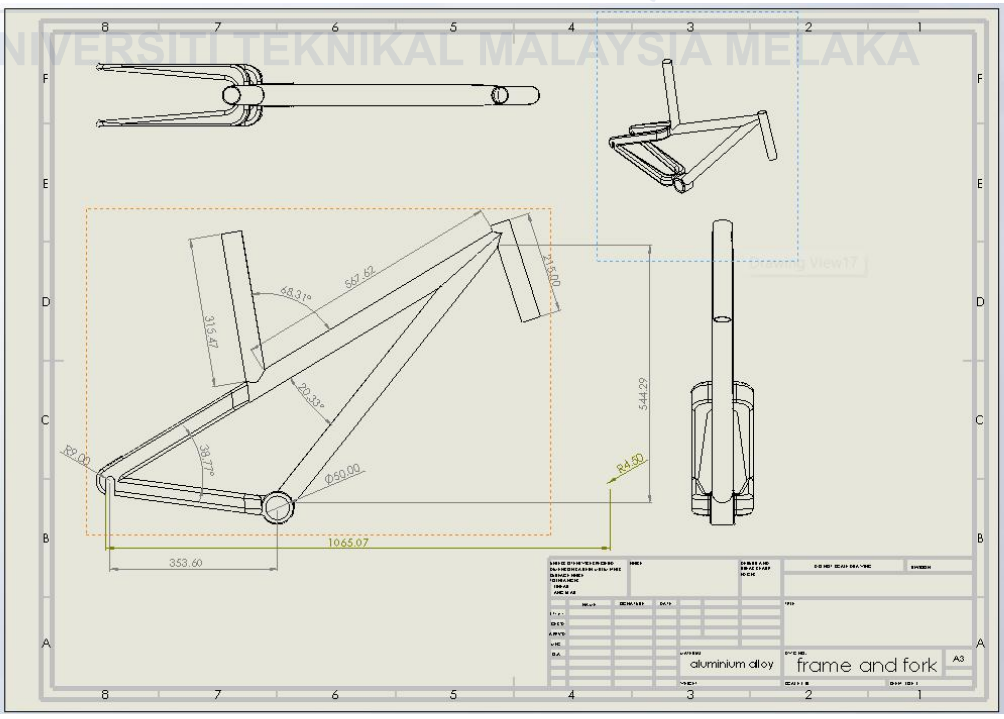


Figure 3.16 Orthographic drawing of the frame and fork system

Table 3.8 Dimension of the bicycle frame

Part No.	Parts	Length(mm)	Dia.(mm)
1	**Head Tube**	**215**	**37**
2	**Top Tube**	**567.62**	**40**
3	**Seat Tube**	**315.47**	**40**
4	**Down Tube**	**695.39**	**40**
5	**Bottom Bracket**	**70**	**50**
6	**Chain Stays**	**353.6**	**40**

Steering System:

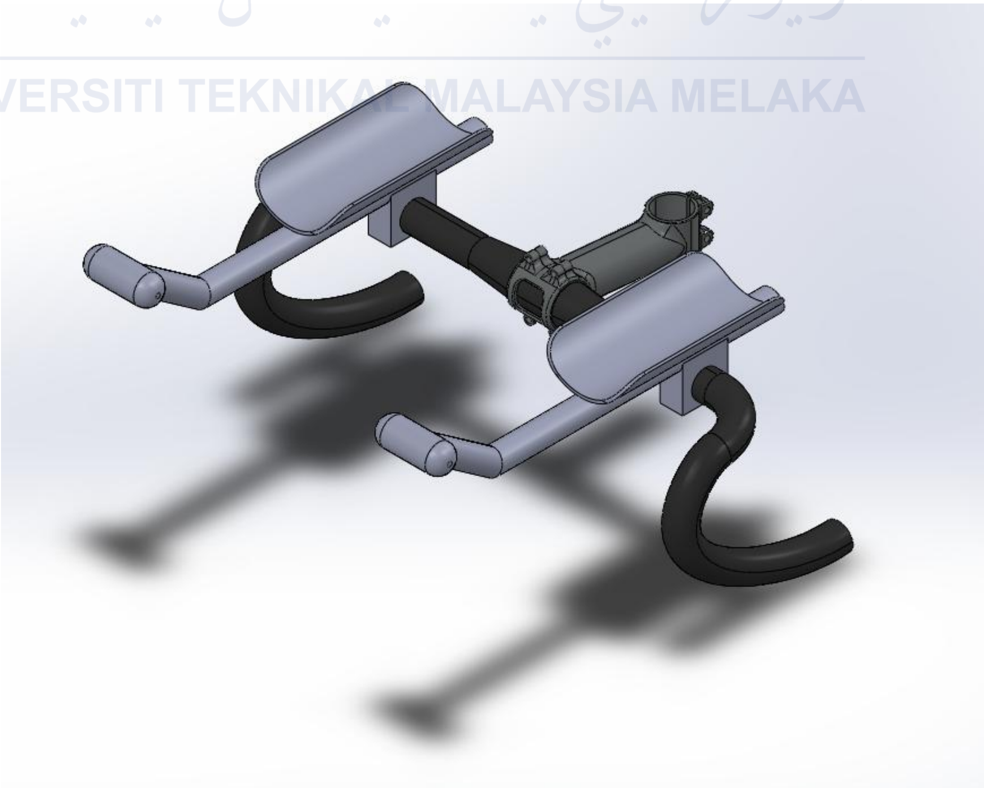


Figure 3.17 CAD model of the handlebar

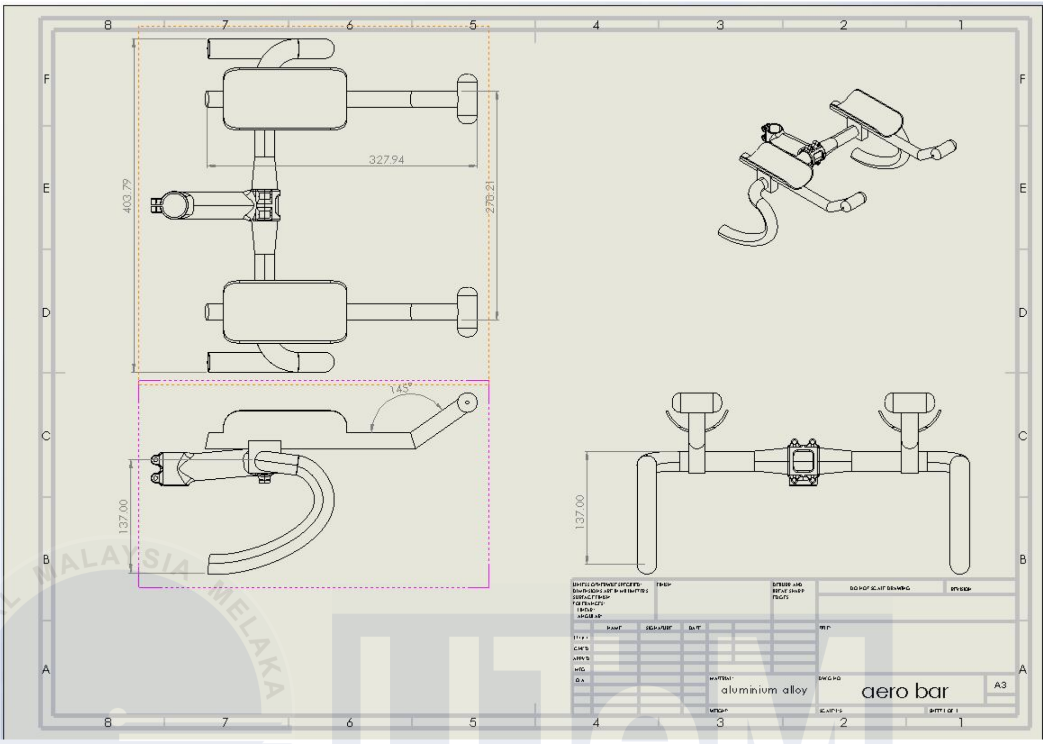


Figure 3.18 Orthographic drawing of the handlebar

Seating System:

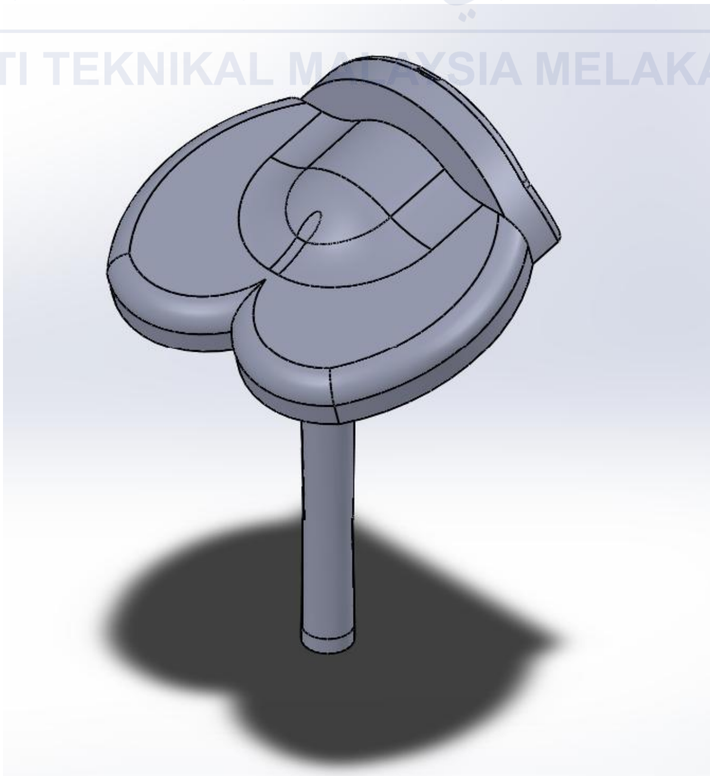


Figure 3.19 CAD model of the saddle and seat post

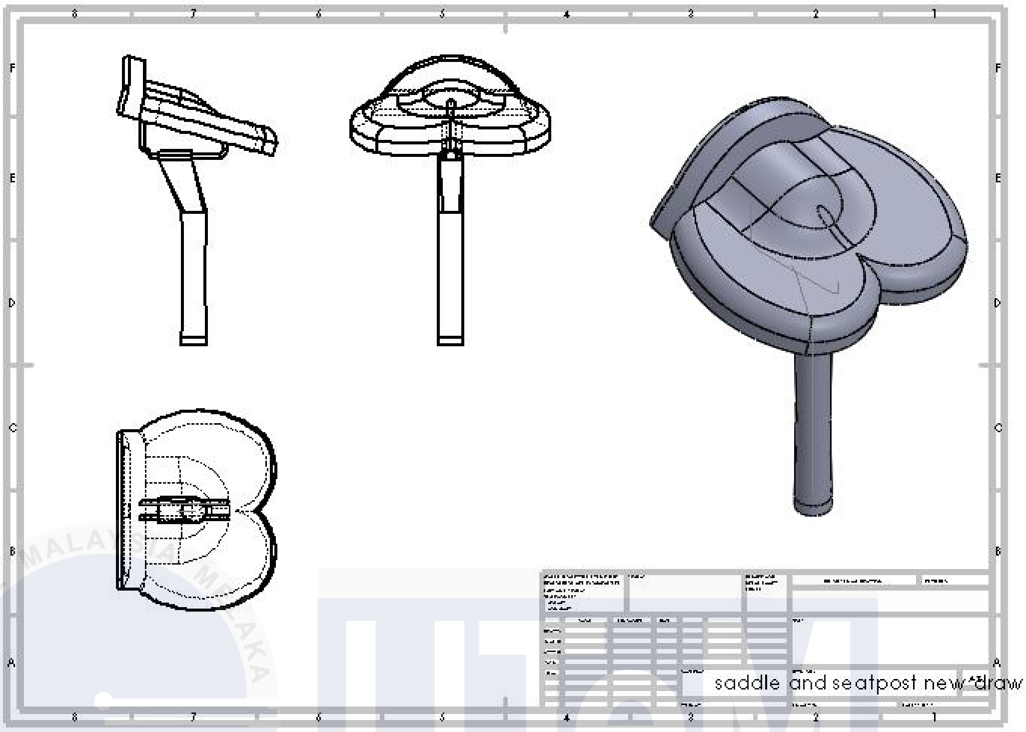


Figure 3.20 Orthographic drawing of the saddle and seat post

3.8 Preliminary Result

This section presents the preliminary results obtained from early stages of the modeling, analysis, and validation processes. These results provide insight into the initial performance of the bicycle design and highlight areas for improvement, forming the basis for subsequent modifications and comprehensive testing.

3.8.1 Preliminary FEA analysis

The initial finite element analysis (FEA) conducted in Ansys on the bicycle frame under various loading conditions indicates that: Structural Integrity: Despite the proposed ergonomic adjustments, the frame maintains its structural integrity, meeting necessary safety standards.

The selection of mesh element size is crucial for accurate results. The appropriate mesh size depends on several factors, including the complexity of the geometry, the type of analysis being conducted, the areas of interest, and the material properties. In this section, 0.01mm meshing size as shown in figure 3.21 is chosen for the analysis to efficiently perform a detailed and accurate FEA of a bicycle frame in ANSYS.

Figure 3.21 Meshing size of 0.01m

The maximum deformation of the bicycle frame is 0.00048776 m as shown in the figure 3.11,and the maximum Von Mises stress of the bicycle frame is 3.7595e7 Pa as shown in the figure 3.12. Different parts of the structure experience different levels of deformation due to the application of loads is right on the seat post and head tube. According to the Wikipedia, the average weight of an Asian people is about 160lbs (60kg), with this the load is set up using this weight and is distributed by 21% of the weight at the head tube while 79% of the bodyweight at the seat tube. Besides, the fixed supports are under the head tube and the chainstay.

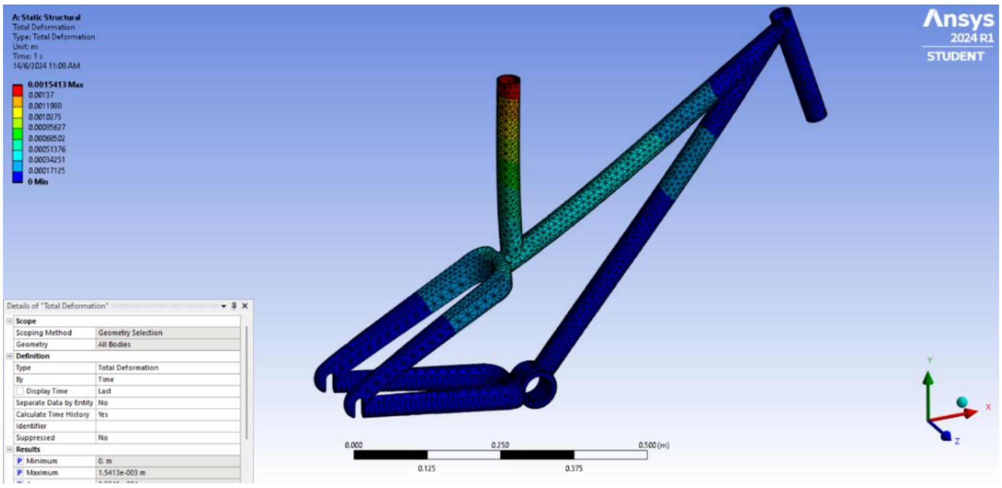


Figure 3.22 deformation of the bicycle frame

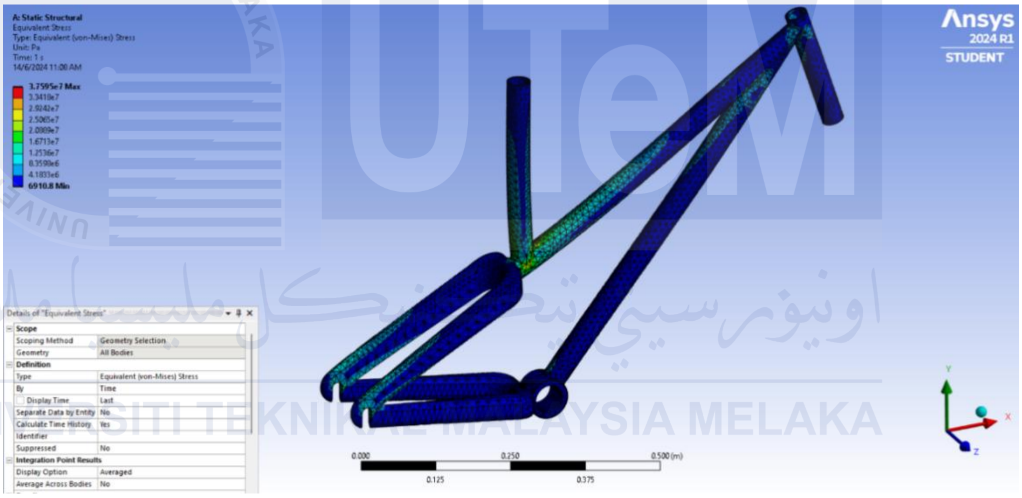


Figure 3.23 Von mises stress of the bicycle frame

3.8.2 Preliminary RULA analysis

The preliminary findings from the RULA analysis in CATIA indicate significant ergonomic concerns with the current bicycle design: Posture Issues: Cyclists often adopt a forward-leaning posture, leading to strain in the lower back and neck.Upper Limb Strain: The current handlebar design causes elevated shoulders and extended wrists, increasing the risk of musculoskeletal disorders which its indicator is shown in Table 3.9. These findings suggest a moderate to high risk for ergonomic injuries, prompting recommendations for design modifications to improve rider comfort and safety.

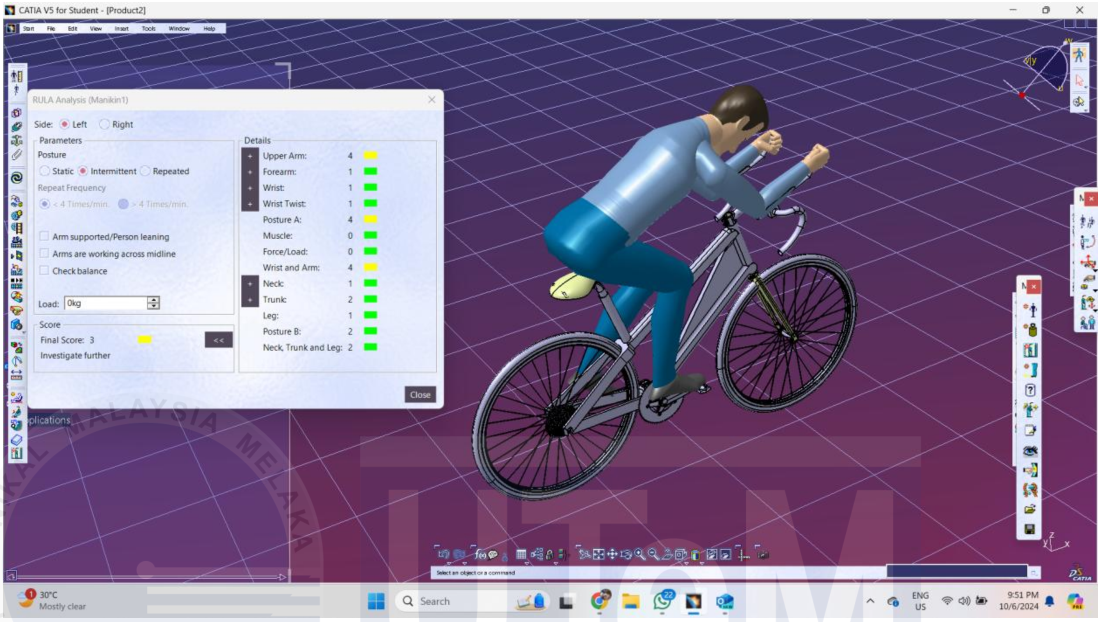


Figure 3.24 Posture of the manikin for RULA analysis

Table 3.9 Level of MSD Risk

Score	Level of Musculoskeletal disorders risk
1-2	Negligible risk, no actions required
3-4	Low risk, change may be needed
5-6	Medium risk, further investigation, change soon
6+	Very high risk, implement change now

In figure 3.25 shown below, the left side of the manikin has scored 2 in the final score in the static posture. While in the figure 3.26 shows the right side of the manikin has scored 2 in the final score in the static posture.

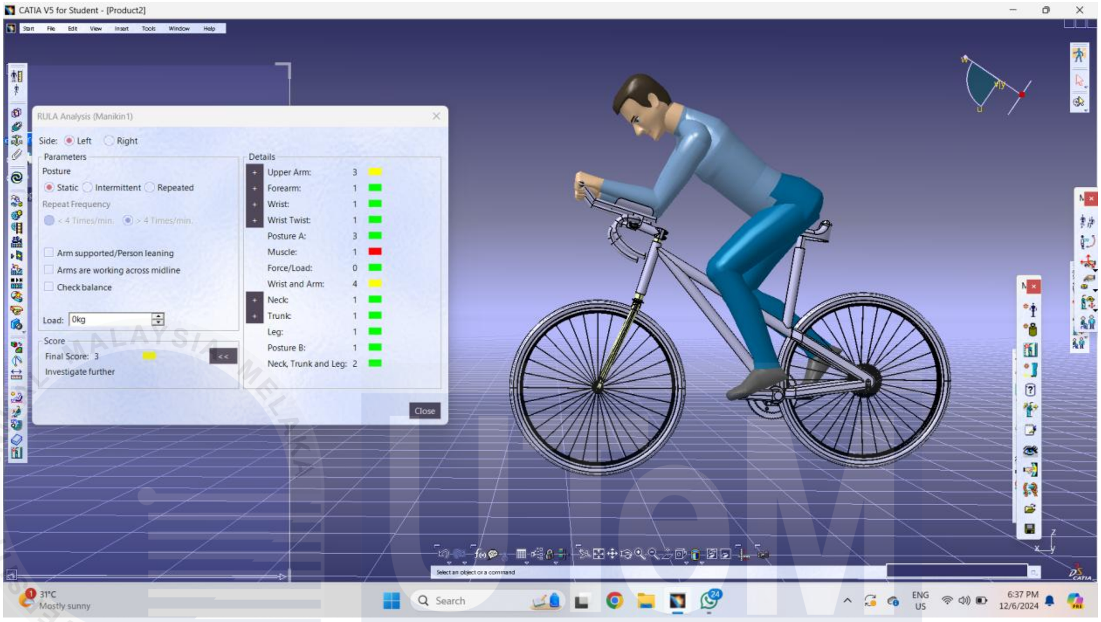


Figure 3.25 Left side score of the manikin

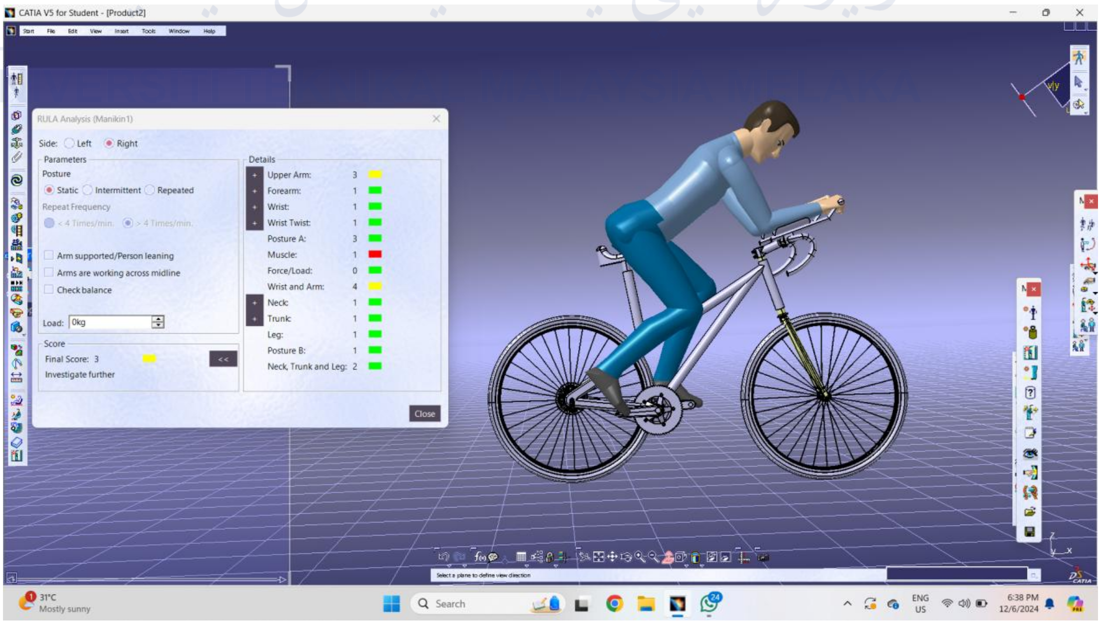


Figure 3.26 Right side score of the manikin

3.8.3 Summary

The ergonomic study using RULA in Catia provided valuable insights into the potential risks associated with the current bicycle design. By identifying and addressing these risks through design modification, the study aimed to enhance rider comfort and reduce the likelihood of musculoskeletal issues. The complementary FEA ensured that these ergonomic improvements did not compromise the structural integrity of the bicycle, resulting in a safer and more comfortable product.

3.9 Modification

This section describes the issues and limitations of the original design and from FEA and RULA analysis. First the goals for this modification are to enhance the rider comfort, and improve the frame durability which are identified from the high stress concentration and poor posture score.

3.9.1 Modeling

This section discusses the bicycle frame's modified measurements, angles, thickness, and materials since these factors have a big impact on the rider's comfort and efficiency. For the technical drawing, (see Appendix D)

Table 3.10 Frame Dimensions and Geometry

Parameter	Value	Explanation
Head tube angle	72°	the steering angle is sensitive for road racing and quick reactions.

Seat tube angle	72°	a small angle in seat tube provides more comfortable riding
Top tube length	520mm	A long top tube is ideal for aggressive riding,
Down tube length	620mm	The frame's total rigidity increases with the length of the down tube. Energy loss can be minimised and force can be transferred to the back wheel more effectively, particularly during pedalling.
Chain stay length	420mm	longer chainstays provide stability.
Material thickness	1.4mm	During high-intensity riding, aluminium alloy material offers the optimum weight-to-rigidity ratio at this thickness.

Table 3.11Material properties of aluminium alloy

Material	Young Modulus (GPa)	Poisson's Ratio	Density (kg/m3)
Aluminium alloy	71	0.33	2770

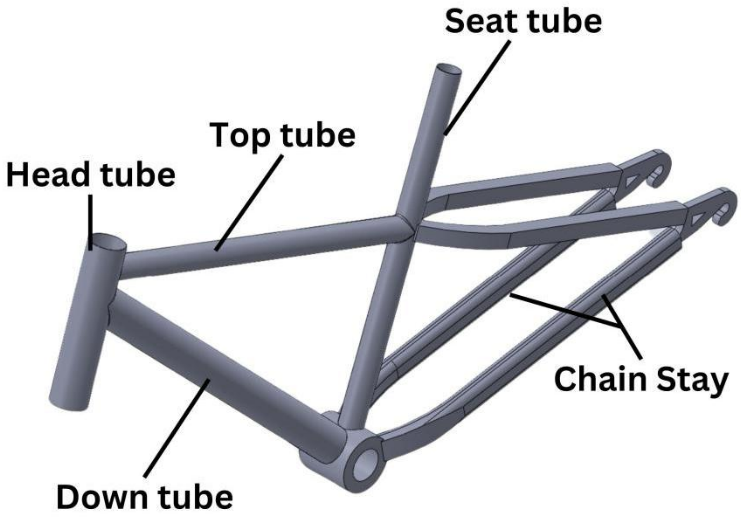


Figure 3.27 3-Dimensional Model of Bicycle Frame

Modified features:

Balance of comfort and rigidity :

The aluminium alloy frame's shorter chainstays and thicker down tube give it exceptional rigidity, making it ideal for stability and effectiveness while pedalling hard. Long rides will be more comfortable because to the carbon fibre front fork's improved shock absorption and weight reduction.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Validation

A journal article by Sajimsha B et al. on Analysis of Mountain Bike Frames by ANSYS is used to validate the current investigation. The current paper's total deformation value during static start-up is 0.027 mm, while the previous study's was 0.02 mm. The current study's equivalent (von-Mises) stress at static start-up is 7.062 MPa, while the previous study's was 7.537 MPa. Upon examination, it is discovered that, under all load conditions, the equivalent (von-Mises) stress and total deformation values derived from the previous study and the current paper closely match as shown in the figure 4.1 and 4.2.

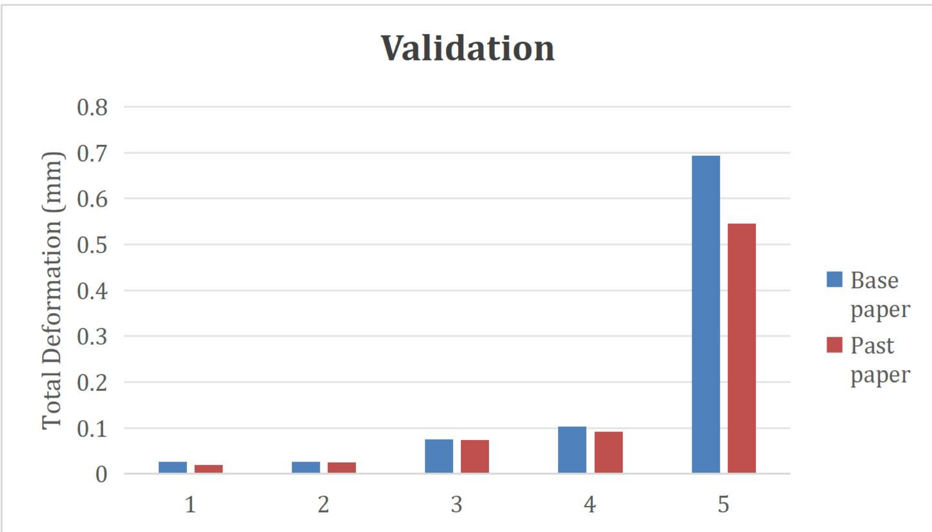


Figure 4.1 Comparison of Total Deformation (mm) in present paper and past study

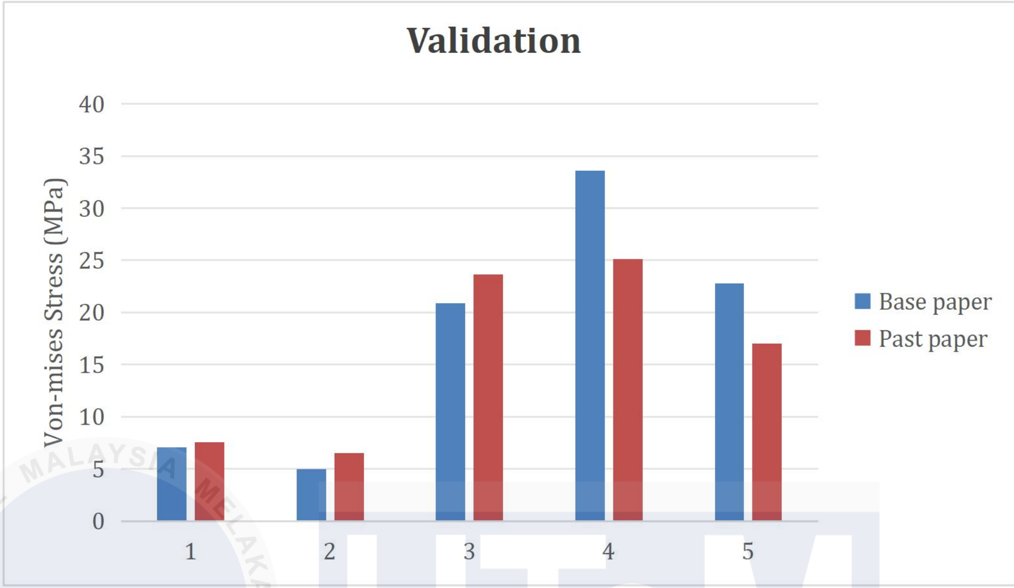


Figure 4.2 Comparison of Von-mises Stress (MPa) in present paper and past study

4.2 Boundary Conditions

To simulate realistic cycling conditions, by applying specific boundary conditions to reflect common scenarios and forces encountered by cyclists.

B1. Static Startup:

When the cyclist starts moving from a static position, this state simulates the forces acting on the frame and other components.

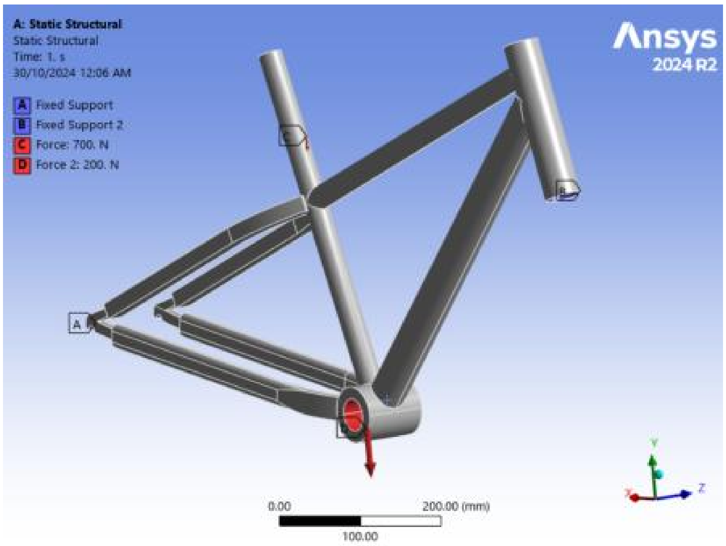


Figure 4.3 Static Start-up

B2. Steady-State Pedaling:

When the cyclist starts continuously cycling ,the dynamic forces are applied, focusing on power transfer efficiency and structural stability.

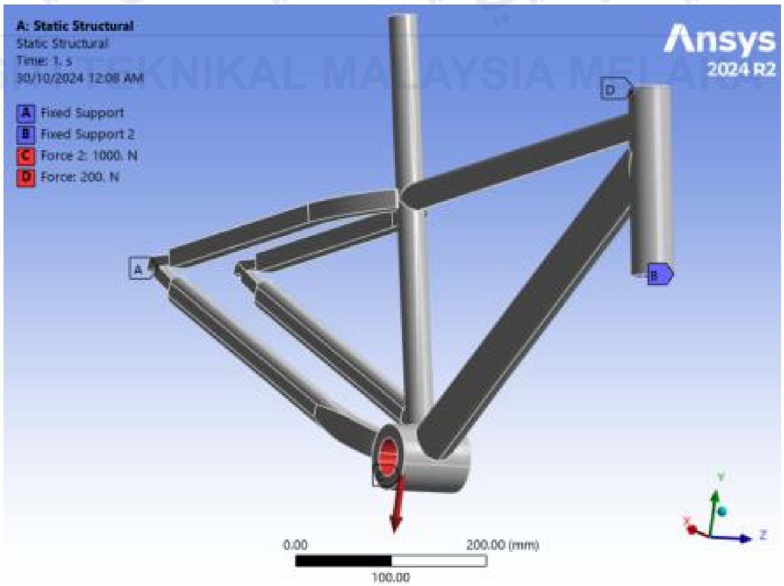


Figure 4.4 Steady state padelling

B3. Vertical Impact:

When riding over bumps or uneven surfaces, this boundary condition simulates vertical forces, affecting frame integrity and rider comfort.

Figure 4.5 Vertical Impact

B4. Horizontal Impact:

When sudden braking or encounter road obstacles , horizontal forces from them are modeled to examine the frame’s lateral stability and stress distribution.

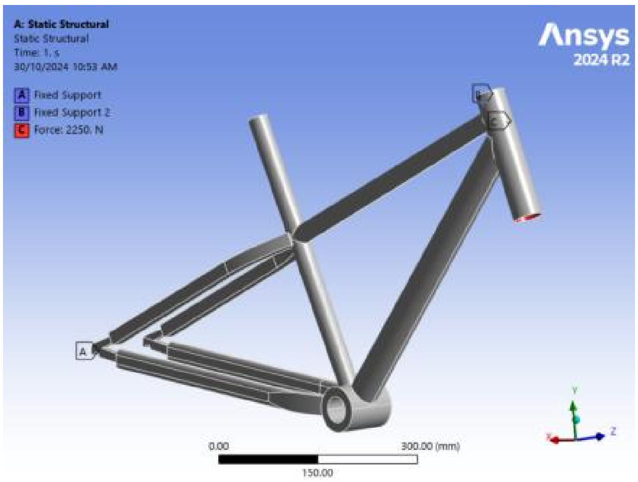


Figure 4.6 Horizontal impact

B5. Rear Wheel Braking:

When the rear frame and wheel under braking, this boundary condition stimulates the forces and stresses experienced by the frame, evaluating the frame's durability and the safety of braking components.

Figure 4.7 Rear wheel braking

4.3 FEA Result and Discussion

This chapter presents the results from finite element analysis (FEA) of total deformation and equivalent stress under different mesh densities and boundary conditions. To validate the reliability of the results, a convergence graph is plotted and followed by a discussion on the structural implications.

4.3.1 Result of Total Deformation Analysis

The total deformation results were obtained for different mesh sizes (8mm, 5mm, 1mm, 0.8mm, and 0.6mm) under various boundary conditions:

Static Start-up: Deformation values for static start-up ranged from 0.204mm (8mm mesh) to 0.21mm (1mm and finer meshes). This minimal increase with finer meshes suggests that static start-up loading does not significantly impact deformation.

Static State Paddling: Similar to static start-up, static state paddling yields low deformation values (0.085mm to 0.086mm across all meshes). This condition results in minimal structural displacement, indicating strong resilience under repetitive, low-force conditions.

Vertical Impact: Deformation under vertical impact ranges from 0.644mm (8mm mesh) to 0.664mm (1mm and finer meshes). This increase shows the model's sensitivity to vertical forces, with finer meshes capturing deformation more precisely.

Horizontal Impact: Horizontal impact produces the highest deformation values, increasing from 0.678mm (8mm mesh) to 0.76mm (1mm and finer meshes), highlighting the structural vulnerability to lateral forces and the importance of mesh refinement for capturing local deformations.

Rear Wheel Paddling: Rear wheel paddling deformations range from 0.69mm (8mm mesh) to 0.694mm (1mm and finer meshes). The small increase across finer meshes indicates this load condition does not require extreme mesh refinement for accurate deformation assessment.

Table 4.1 The results for each condition are visualized in Table 1

	Coarse mesh (8mm)	Medium mesh (5mm)	Fine mesh (1mm)	Finer mesh (0.8mm)	Finest mesh (0.6mm)
Static Start-up	0.204mm	0.207mm	0.21mm	0.21mm	0.21mm
Static state padelling	0.085mm	0.086mm	0.086mm	0.086mm	0.086mm
Vertical Impact	0.644mm	0.655mm	0.664mm	0.664mm	0.664mm
Horizontal Impact	0.678mm	0.732mm	0.76mm	0.76mm	0.76mm
Rear wheel padelling	0.69mm	0.692mm	0.694mm	0.694mm	0.694mm

4.3.2 Results of Equivalent Von-Mises Stress

The equivalent stress results across mesh sizes highlight how mesh refinement influences stress accuracy under different loading conditions:

Static Start-up: Equivalent stress ranges from 16.92 MPa (8mm mesh) to 29.52 MPa (0.6mm mesh). The higher values for finer meshes reveal areas of stress concentration that coarser meshes might overlook.

Static State Paddling: Stress values for static paddling show moderate increases with mesh refinement, from 11.853 MPa to 17.94 MPa. This stability suggests that even in static paddling, areas of stress concentration benefit from finer meshes.

Vertical Impact: Vertical impact stress rises from 54.109 MPa (8mm) to 94.43 MPa (0.6mm). This large increase illustrates that vertical impacts create significant localized stresses, which finer meshes capture more effectively.

Horizontal Impact: The highest stress values occur under horizontal impact, reaching up to 160.55 MPa with the 0.6mm mesh. The significant increase with mesh refinement underscores the need for finer meshes to capture stress peaks accurately.

Rear Wheel Paddling: Stress under rear wheel paddling gradually increases from 18.507 MPa to 32.26 MPa, suggesting that even moderate forces benefit from finer meshes for more accurate stress readings.

Table 4.2 The results for each condition are visualized in Table 1

	Coarse mesh (8mm)	Medium mesh (5mm)	Fine mesh (1mm)	Finer mesh (0.8mm)	Finest mesh (0.6mm)
Static Start-up	16.92MPa	19.07MPa	24.59MPa	29.17MPa	29.52MPa
Static state padelling	11.853MPa	11.97MPa	13.96MPa	13.76MPa	17.94MPa
Vertical Impact	54.109MPa	60.99MPa	78.64MPa	93.33MPa	94.43MPa
Horizontal Impact	109.32MPa	122.8MPa	150.4MPa	154.4MPa	160.5MPa
Rear wheel padelling	18.507MPa	22.57MPa	26.16MPa	28.11MPa	32.26MPa

4.3.3 Convergence Analysis

Convergence analysis helps validate the accuracy and reliability of FEA results by observing how deformation and stress stabilize with mesh refinement and the line graph in plotted in figure 4.8

Total Deformation Convergence

The total deformation results achieve convergence under both static and impact loading conditions:

Static Loading Conditions: Deformation in static start-up and paddling stabilizes at the 1mm mesh size, with finer meshes yielding no significant changes. This suggests that a 1mm mesh provides sufficient accuracy for low-force scenarios, balancing precision and computational efficiency.

Impact Loading Conditions: Deformation under vertical and horizontal impacts stabilizes at finer meshes (1mm and smaller), indicating convergence. However, differences beyond the 1mm mesh are minimal, making 1mm sufficient for accurate deformation under these conditions.

Equivalent Stress Convergence

Equivalent stress values also achieve convergence, with stability in results as mesh size decreases:

Static Loading Conditions: Stress values for static loading converge around 1mm mesh size, showing only minor increases with finer meshes. This supports using a 1mm mesh for static loads.

Impact Loading Conditions: Horizontal impact requires finer meshes for convergence, with stress stabilizing at 0.6mm. This suggests that finer meshes are essential under high-impact scenarios to ensure accuracy in stress predictions.

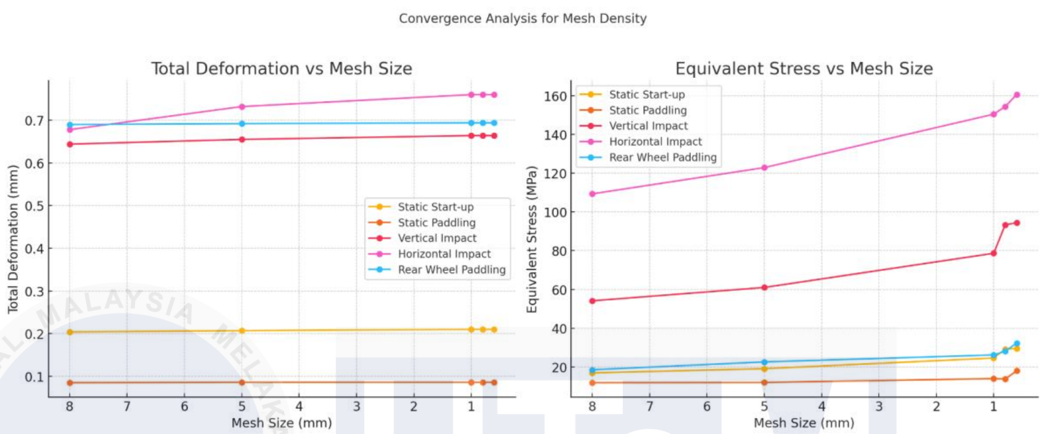


Figure 4.8 Convergence Analysis for Mesh Density

4.4 RULA Analysis Results and Discussion

The RULA analysis made quantitative scores that show the ergonomic impact of the bicycle design on the rider's posture. The key findings are summarized as follows:

Initial Design Scores:

- Upper Body (Neck, Shoulders, and Upper Arms): High risk due to forward-leaning posture and limited adjustability of the handlebar.
- Lower Body (Wrists, Elbows, and Hands): Moderate risk due to improper saddle height, leading to extended reach and wrist strain.
- Overall Score: Rated in the "Investigate further" category which is an average score of 3 , indicating a need for the ergonomic adjustments.

· **Modified Design Scores**:

- Upper Body: Improved scores due to optimized handlebar position and reduced forward lean.
- Lower Body: Reduced strain with a suitable height saddle, minimizing the reach distance.
- Overall Score: Rated in the "Acceptable" range which is an average score of 2, reflecting lower ergonomic risk and improved posture alignment.

4.4.1 Key Postural Adjustments

The results indicate significant improvements in rider posture due to the modifications made to the bicycle design:

Handlebar Position: Adjustability allowed riders to maintain a neutral shoulder and elbow position, reducing strain.

Saddle Height: Optimized saddle height minimized forward lean, improving neck and lower back posture.

Weight Distribution: Improved frame geometry and adjustable components ensured better weight distribution across the upper and lower body, reducing wrist and hand strain.

4.4.2 Comparative Results

Table 4.3 RULA Score at Right Side

Parameter	Initial Design	Modified Design	Improvement
Upper arm	3	2	~66%
Forearm	1	1	~0%
Wrist	1	1	~0%
Wrist twist	1	1	~0%
Posture A	3	2	~66%
Muscle	1	0	~100%
Force	0	0	~0%
Wrist and arm	4	2	~50%
Neck	1	1	~0%
Trunk	1	1	~0%
Leg	1	1	~0%
Posture B	1	1	~0%
Neck, Trunk and Leg	2	1	~50%
RULA Overall Score	3	2	~66%

Table 4.4 RULA Score for left side

Parameter	Initial Design	Modified Design	Improvement
Upper arm	3	2	~66%
Forearm	1	1	~0%
Wrist	1	1	~0%
Wrist twist	1	1	~0%
Posture A	3	2	~66%
Muscle	1	0	~100%
Force	0	0	~0%
Wrist and arm	4	2	~50%
Neck	1	1	~0%
Trunk	1	1	~0%
Leg	1	1	~0%
Posture B	1	1	~0%
Neck, Trunk and Leg	2	1	~50%
RULA Overall Score	3	2	~66%

4.4.3 Discussion

The findings from the RULA analysis highlight critical aspects of the design's impact on rider posture and musculoskeletal health:

Effectiveness of Modifications: The reductions in RULA scores show how well handlebar position, saddle height, and frame shape can be improved. The ergonomic risks associated with the original design were successfully decreased by these modifications.

Comfortability of Rider: Manikins' responses support the RULA findings, showing increased comfort and less discomfort.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The goal of this study was to optimise the design of a bicycle for Southeast Asian riders by taking consideration of important factors like ergonomic comfort and structural integrity. Based on the objectives mentioned and the results collected, the following conclusions were reached:

Critical stress points and deformation areas in the original design were identified by the structural evaluation. According to FEA validation, modifications such as reinforced joints and optimised material thickness greatly enhanced stress distribution and fatigue life.

Due due to incorrect saddle height and handlebar reach, the ergonomic evaluation found high-risk postures in the original design. better RULA ratings indicate that design changes, such as better frame geometry, decreased ergonomic hazards. The project advances into the field of bicycle design by showing a comprehensive strategy for optimising both ergonomic and structural performance. The significance of user-centred design is emphasised by this study, especially in areas with significant environmental and cultural factors. The finished design encourages broader adoption of cycling as a sustainable form of transportation by making riding safer and more comfortable.

5.2 Recommendations

Even though this project met its goals, several restrictions and potential areas for improvement were highlighted. The following suggestions are presented in order to address the problems and increase the study's scope:

Perform comprehensive field testing in a range of environmental circumstances with a wide variety of riders. Gather information on performance, comfort, and long-term durability to validate the design. Utilise dynamic motion studies, such as wearable sensor technologies or video-based posture analysis, to enhance the RULA study and provide real-time information on the biomechanics of cyclists. To increase the design's applicability, make modifications for cyclists participating in intense or competitive riding situations, including mountain biking or racing.

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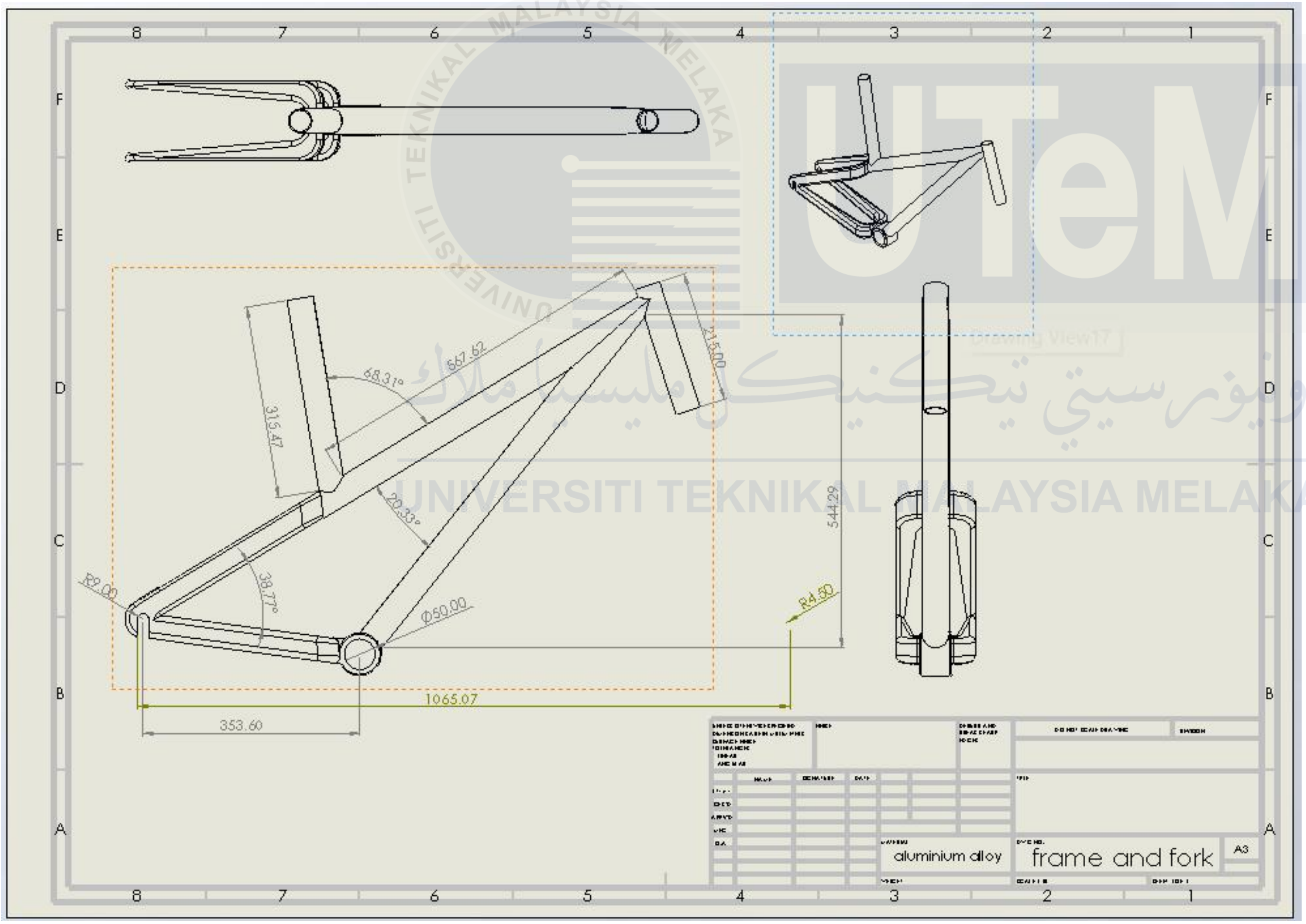
APPENDIX A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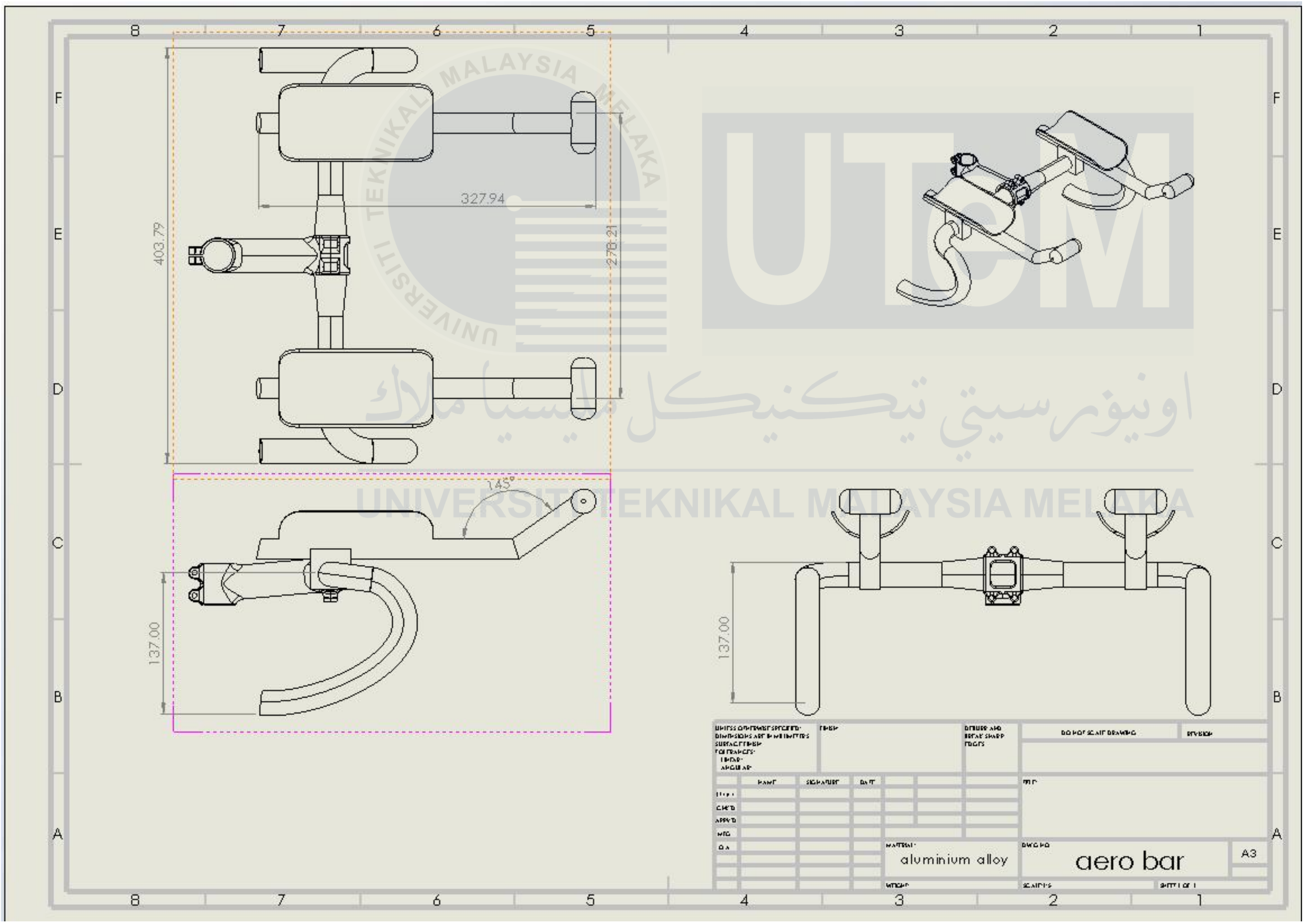
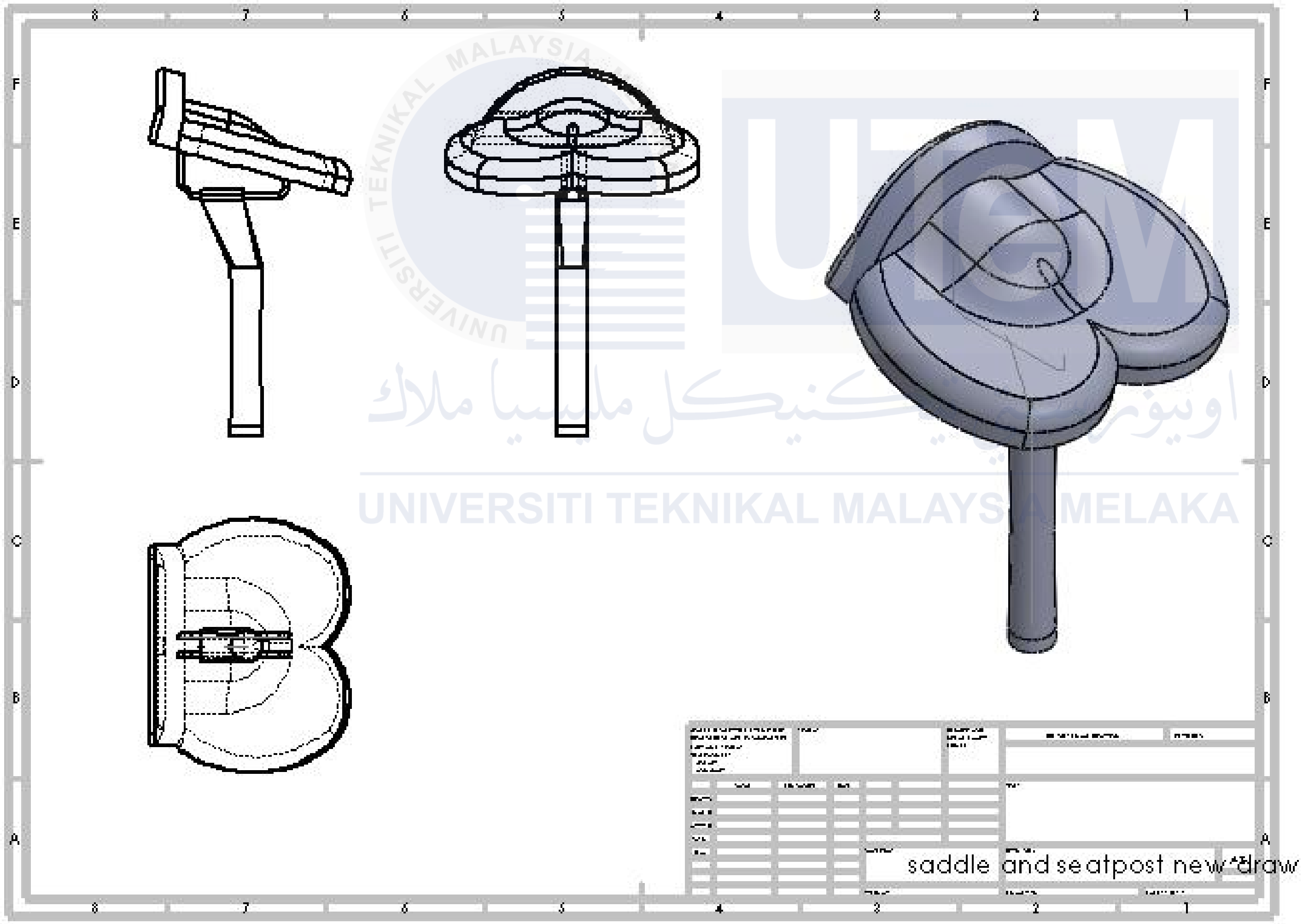
315.47
215.00
20.33°
38.77°
R9.00
Ø50.00
R4.50
544.29
1065.07
353.60
aluminium alloy
frame and fork
A3

APPENDIX B



403.79
327.94
278.21
145°
137.00
137.00
aluminium alloy
aero bar
A3

APPENDIX C



APPENDIX D