Cape Peninsula University of Technology

M.Tech - Industrial Design Department

DESIGN OF A NEW PROTECTIVE ISOLATING SIDE-DOOR: A VIRTUAL MODEL TO SIMULATE INGRESS AND EGRESS MOTION FOR MICRO-MOBILITY VEHICLES.

by

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DECLARATION

I, Neil de Vos, declare that the contents of this thesis represent my own unaided work, and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed **Date**

ABSTRACT

This paper is positioned within the broader context of public transportation systems, with specific focus on the development of urban micro first and last mile mobility solutions, and what it could mean for individuals and the economy.

Globally, urban problems such as traffic congestion, poor public transport integration, and carbon emissions are forcing us to rethink traditional means of transport. Large fossil-fuelled vehicles and limited public transport infrastructure characterize South Africa's transport market. Despite the growth in car use, public transport and walking are still the predominant "lifeline" forms of mobility for the vast majority of South Africans in order to access work, schools and services.

Moreover, the lack of public transport services in key economic corridors and rural areas of South Africa, the role of the metered taxi industry which is currently effectively limited to serving only the needs of the tourist market due to high charging regimes, and finally, the absence of an effective inner city transport system endorses the lack of first and last mile transportation solutions, and the integration thereof with other transport mediums. This adds to the conflict commuter's face on a daily basis in obtaining a seamless distribution of transport services.

80% of trips in urban areas are less than 3km, placing urban micro mobility vehicles in an ideal position as a solution to transportation. This describes the investigation conducted into micro-mobility trends within South Africa to identify a key mode of transport that would comply with the stated requirements, and allow accessibility to commuters within the city and to the surrounding communities.

In 2014, Mellowcabs, which are electric public transport vehicles that provide first and last mile transport services, was identified as a promising candidate within the local micro-mobility vehicle context. They were in need of a design input for their immediate next requirement, which thus describes the development of a good protective side door system that would isolate passengers in adverse weather conditions, whilst similarly affording comfort and safety features found in normal passenger vehicles.

The design process is focused on creating a new side door, however, at the same time the product should be, elegant, smart, fashionable, comfortable, economical, maneuverable and safe. In addition, the virtual product lifecycle management tool, CATIA, allows the design team to get feedback in terms of physical-based data that correspond to how the door could hinder the passengers interaction while they ingress and egress the vehicle. This enables us to try various designs to perform a comparative study without building a single physical prototype.

Very little attention has been given to simulating ingress and egress movement for micro-mobility vehicles. For the purpose of this research paper in performing an ergonomic evaluation of the Mellowcabs design and proposing recommendations for improvement, a virtual model to perform ingress and egress motion had been developed. Additionally it aims to understand who the commuters are that occupy this method of transportation, and gain knowledge of their ingress and egress patterns.

KEYWORDS

Keywords	Definitions
Ingress	The act of entering
Egress	The act of coming (or going) out
Automotive Ergonomics	The study of how automotive vehicles can be designed better for human use
Digital Human Modeling	Software representations of humans, to perform the analyses for complex situations
Anthropometrics	Of or relating to anthropometry of the human body
Occupant Packaging	The interior design process of a vehicle to achieve a good level of accommodation, comfort and safety for passengers
Vehicle Packaging	A method to safeguard and protect space for the human user and necessary components that make up the vehicle being designed
H-Point	The Hip-Point is the theoretical, relative location of an occupant's hip: specifically the pivot point between the torso and upper leg portions of the body
Mobility	The quality of moving freely
Micro-mobility	Micro-mobility tends to deal with situations where a subscriber is seamlessly moving between two points of attachment that are part of the same network

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TABLE OF CONTENTS

LIST OF TABLES AND FIGURES

CHAPTER 1

1.0. INTRODUCTION

Due to micro-mobility vehicles (MMV's) representing an entirely new class of vehicles and requires unique vehicle classification, few studies exist on the development of their design or the design of peripheral accessories.

1.1. STATEMENT OF RESEARCH PROBLEM

The application of *Virtual Ergonomics Analysis* in *Industrial Design*: to evaluate the Ingress and Egress motion of passengers for a micro-mobility vehicle.

The design of ingress and egress systems for MMV's is an area that deserves the attention of Industrial Designers and Ergonomists. Although the design of MMV's vehicles requires consideration of human safety and comfort, very little attention has been given to simulating ingress and egress movement and performing human posture analysis for these vehicles.

1.2. MAIN RESEARCH QUESTION

How can Industrial Designers utilize virtual posture analysis for the evaluation of ingress and egress ergonomics of passengers entering and exiting a MMV, and to validate the practicality and plausibility of the final door-, and entry design?

1.3. SUB-QUESTIONS

1.3.1. Which current trends are seen as elegant, smart and fashionable amongst the emergent MMV group in the automotive industry?

1.3.2. What are the current automotive weather isolating door design trends in terms of quality, aesthetics, ergonomics and safety?

1.3.3. What are the unique characteristics of ingress and egress motions for a MMV, and can those movements be simulated by a virtual digital manikin?

1.4. BACKGROUND

1.4.1. CONTEXT

This thesis is positioned within the broader context of public transportation systems, with specific focus on the development of urban micro first and last mile mobility solutions, and what it could mean for individuals and the economy. Growing up in South Africa, access to public transport, and still today with its current development, seems to be a struggle.

Globally, urban problems such as traffic congestion, poor public transport integration, and carbon emissions are forcing us to rethink traditional means of transport. Large fossil-fuelled vehicles and limited public transport infrastructure characterize South Africa's transport market. Despite the growth in car use, public transport and walking are still the predominant "lifeline" forms of mobility for the vast majority of South Africans in order to access work, schools and services. 80% of trips in urban areas are less than 3km, placing urban micro-mobility vehicles in an ideal position as a solution to transportation.

Moreover, the lack of public transport services in key economic corridors such as the Northern axis, servicing Milnerton, Tableview, Blaauberg and Parklands, adds to the conflict commuter's face on a daily basis. In addition, the role of the metered taxi industry is currently effectively limited to serving only the needs of the tourist market due to high charging regimes. These pricing structures effectively exclude the use by local Capetonians. Finally, the absence of an effective inner city transport system endorses the lack of first and last mile transportation solutions, and the integration thereof with other transport mediums in facilitating seamless distribution services within the city and to the surrounding communities.

The *Mellowcabs* MMV is an all-electric three seat, two passenger commuter vehicle. It is promoted as a first and last mile vehicle, providing on demand, quick and comfortable inner city transportation for locals as well as tourists. Its design is predicated on 80% of urban taxi commutes being less than 3km (Mellowcabs, 2014).

The level of novelty provided by the Mellowcab's vehicle and its competitors can be classified as a 'disruptive innovation', which according to the OECD's Oslo Manual (2005) is defined as, "An innovation that has a significant impact on a market and on the economic activity of firms in that market." (Selhofer, Arnold, Lassnig, Evangelista, 2012:18)

As such a definitive category does not yet exist for the *Mellowcabs* style of commuter vehicle. For the purposes of this thesis it will be positioned according to Frost and Sullivan's categorisation of current MMV's (Shankar, 2012). Few of these MMV's, whether in similar homologation classes or not, have permanent doors and almost none have operable windows. Given that they are projected to expand rapidly into global markets where changing weather is of concern, there exist an opportunity to provide a more permanent, higher quality solution for this class of vehicle. Amsterdam has plans for at least ten thousand electric vehicles in 2015; with the number of charging point in major European cities already amounting to greater than 857 in London, 735 in Oslo, 458 in Paris, 245 in Amsterdam, 76 in Barcelona and 66 in Dublin (Di Salvo, 2012). The biggest projected markets for MMV's include China and Europe where weather protection will be of great importance (Shankar, 2012).

As a disruptive technology, this vehicle also represents a major departure for consumers as compared to traditional style vehicles. It is thus important that the design process not necessarily rely on only that of affordances and familiarities tied to existing classification of vehicles.

The *Mellowcabs* vehicle is not intended to be used as a single owner vehicle and thus will need to cater for a larger demographic. However user profiles for single owner MMV's such as the *Renault Twizzy* and *Toyota iRoad* will be investigated for parallels as they are considerably closer in terms of their design considerations when compared to the traditional class of vehicle.

The design of ingress and egress systems for MMV's is an area that deserves the attention of designer and ergonomists. By utilizing parametric CAD software it is possible to predict the outcome of various human factor related issues without having to physically create prototypes.

By investigating the attributes of a manikin in a given virtual environment (3D space), designers and engineers can generate a better understanding of the constraints and needs of the occupant.

The Mellowcab MMV door development design project is under the design supervision of the *PLMCC* (Product Lifecycle Management Competency Centre). The Centre makes use of *Dassault Systeme's (DS) CATIA V6* CAD software. Apart from being able to design parts and assemblies of products as one would be able to do in most conventional parametric solid modelling software packages, specialised workbenches within DS *CATIA V6* allow designers and engineers to simulate and design situations specifically pertaining to human factors. This enables the design team to design "around" a specific percentile human user.

1.4.2. MOTIVATION

Motivation for an accessible zero-emission vehicles specifically addressing first and last mile transportation for public transport users and facilitating seamless distribution services within the city and to the surrounding communities has lead the initial aim of the study to identify and evaluate adequate MMV solutions, which in effect would:

- Introduce the use of a locally based and long lasting mobility system for low-income contexts in Africa.
- Reduce South Africa's dependency on cars, reduce traffic, and positively contribute to inner city transportation.
- Provide an affordable alternative transport mode to South Africans in order to counteract rising fuel costs in commuting, as well as empowering individuals in business and allowing corporate to improve their service offerings in a cost effective manner.

- Improve the objectives of first and last mile transport solutions to work with other transport mediums in facilitating seamless services within the city and to communities, as a way to reduce the need for fossil-fuelled cars.

In addition, it has been established that the development of a MMV as a key mode of transport should comply with the following characteristics as displayed in the figure below (Figure 1.1).

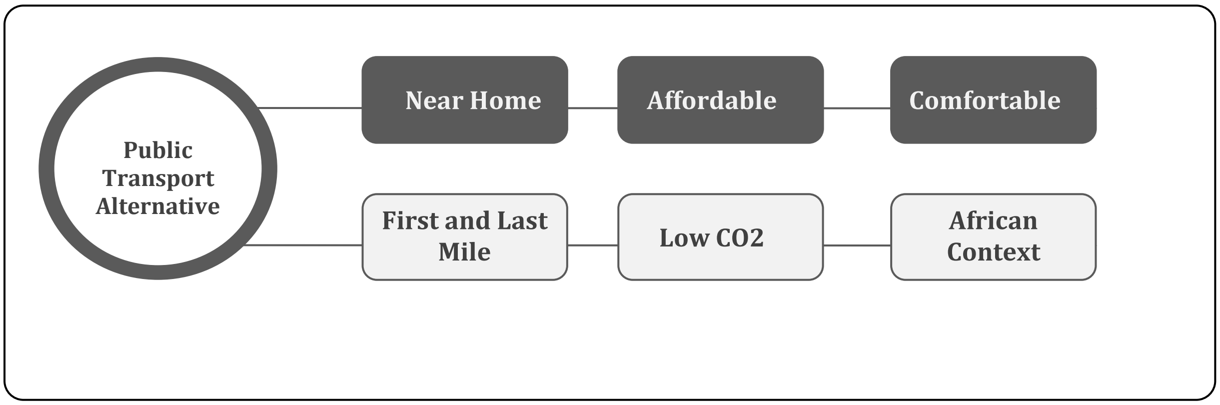


Figure 1.1: Motivation and Characteristics for a locally based MMV (Image by Author, 2015)

1.5. OBJECTIVES OF RESEARCH

1.5.1. To develop a virtual simulation of a digital human model to perform ingress and egress motion for MMV's.

1.5.2. To study the responses of passengers with different anthropometries during ingress and egress of MMV's.

1.5.3. To provide information on the most relevant ingress and egress patterns with respect to MMV geometry (seat height, sill width) and corresponding driver characteristics (age, height, weight) and,

1.5.4. To evaluate human comfort using a posture analysis associated with MMV ingress and egress motion, and to quantify the effects of the fundamental design parameters of the side-door.

1.6. DELIMITATION

There are several limits to the study that may reduce overall exploration of the final product. The ability of 3D CAD software to incorporate virtual manikins in the design process has its advantages. However, it is extremely unlikely that CAD based manikins can simulate every conceivable human scenario (Curtney, 2011). The cognitive response of the manikin is also non-existent. While it serves as a tool for designers to evaluate certain human factors applications, it certainly does not do so for all conceivable scenarios. The software, although catering for a vast range of percentiles, may exclude some cases of physical disability.

When considering aspects of human emotion and semantics, virtual manikins cannot be utilized. The way the virtual manikin will interact with controls and its environment is thus of a mechanical and or physical nature and not a psychological one.

For the purpose of this study, the development of a virtual model to perform ingress and egress motion for a locally based MMV, will solely focus on their passenger vehicle class only and not that of the Cargo specified vehicles. Thus testing will be done for passenger occupants only, and not simulate that of the drivers.

Furthermore this thesis does not expand on crashworthiness, but solely focuses on the design of a protective side door system that would isolate passengers in adverse weather conditions, and would not hinder their ingress and egress movement from and to the vehicle.

Even though this product will be developed with a view of expanding into other markets, particularly France and the United Kingdom; Cape Town will predominantly be used to conduct ethnographic research.

While the design of mechanisms, their layout and attachment methods will be proposed, in-depth evaluation of their mechanics will not be dealt with. Material development will not be explored; any materials proposed should be commercially available.

1.7. SUMMARY

Chapter 1 had introduced the problem and motivation for the study. It provided a brief background of the context, and of previous engineering or design work on the topic. It outlines the purpose, motivations, and specific objectives of the project, which acts as a ‘road map’ for the rest of the thesis. Additionally, the delimitations to this project are presented. Thus, the previous section highlights that the design of ingress and egress systems for MMV’s is an area that deserves the attention of Industrial Designers and Ergonomists.

In the following chapter, the Investigation Review will analyse and investigate existing micro-mobility trends and the consumers’ perception towards them. And the Literature Review section highlights that of: automotive ergonomics, door design, effect on design, vehicle ingress and egress, and human factors digital modelling for virtual motion simulation.

CHAPTER 2

2.0. INVESTIGATION & LITERATURE REVIEW

With the MMV sector being fairly new, classified as a 'disruptive innovation' and its target audience ill defined, the Investigation Review will analyse and investigate existing micro-mobility trends and the consumers' perception towards them. Determining which qualities any proposed side-door design must embody, one needs insight into the needs and expectations of its potential users. Case Study 1: The Case of Portable Digital Music Player looks at why the *Apple iPod*'s design strategy is ideal for developing a product within this emergent market. **S**imultaneously it will attempt to establish how best to approach the task of instilling a sense of quality and safety within the design of a side-door. Case Study 2: The Case of the *e-bike*, discusses the implementation and evaluation of product semantics in the context of a physical product that it is aimed at a similar market niche.

2.1. INVESTIGATION REVIEW

2.1.1. EXISTING MICRO-MOBILITY VEHICLES TRENDS

Several interesting developments have been observed across the automotive-, transportation industry, and its stakeholders. More and more electric, hybrid, and micro-mobility solutions targeted at urban environments continue to be released, and are currently available and quite popular in Europe and United States. *Renault's Twizy* has been in the market in Europe and people are using it like a car. Other examples such as the *Toyota iRoad* and were launched last year. The car sharing market continues to grow, with over 3 million members in 2013, and with a continued evolution of the business model, such as the Harmonious Mobility Network launched by Toyota with the city of Grenoble in France.

Micro-mobility solutions are equally important in the rural areas of South Africa, which are usually not well connected by public transportation systems. There are only very few buses running every hour, and rail systems can be unpredictable, which is inconvenient for the residents, adding that residents in the rural areas relied heavily on individual modes of transportation such as car, motorbike and minibus taxis, even though it is for a short distance.

MMV's are defined as a compact sized vehicle designed for personal mobility with one or two passengers. There are different types of MMV's such as standing, chair, cycle and car-type and most of them run via electricity. Other examples of MMV's within developing countries such as the South African context are the more common electric bicycles, three-wheeled Velomobiles, Pedi cabs, Rickshaws and Tuk-tuks.

For the purpose of this thesis, an investigation of micro-mobility trends within South Africa was conducted to identify a key mode of transport that would comply with the above-mentioned characteristics, and allow accessibility to commuters within the city and to the surrounding communities. The identified companies and modes of transport are as follow (Table 2.1):

Micro-Mobility Vehicles in South Africa		
Initiative	**Owner/Company**	**Link/Source**
MULO/KANGA Project	Hazal Gumus	Thesis
Mellowcabs	Neil du Preez, Cape Town	http://mellowcabs.com/
eZee Electric Bicycles	Antony, City Cycles –Cape Town	http://www.ezeebike.co.za/
ELF	Rob Cotter, Organic Transit	http://organictransit.com/
Monarch Tuksi Company	Clarence Brothers, Cape Town	http://www.monarchtuksi.co.za/
SheshaTuks	Johannesburg	http://sheshatuks.co.za/
TukTuk Auto	Mr Shabeer Adam, Port Elizabeth	http://tuktukauto.co.za/

TABLE 2.1: Investigated MMV trends in South Africa

2.1.2. MELLOWCABS (IDENTIFIED MICRO-MOBILITY VEHICLE)

Neil du Preez, founder and Chief Executive Officer of *Mellowcabs*,is an experienced entrepreneur, having developed and led various businesses, amongst others *Riksha*, a child mobility company. He is passionate about non-motorized transport, and the development of first and last mile transport solutions as a way to reduce the need for fossil-fuelled cars.

Mellowcabs manufactures, and operates attractive, high-tech 100% electric vehicles. *Mellowcabs* are public transport devices, providing first and last mile transport services. Their main source of income is not carrying passengers, but selling advertising space on, and in the vehicles. The *Mellowcabs* vehicles have been designed to be very safe and extremely visible, and to offer optimum advertising space on an aesthetically pleasing design. The *Mellowcabs* vehicles are manufactured from recycled materials, and feature state of the art electric motors and batteries.

Mellowcabs will typically operate in a limited urban radius of 3-4 km, and will not compete with other transport systems such as trains, buses or taxi's, but rather feed into and complement existing networks. A single *Mellowcab* can provide over 120km of transport per day. All of the vehicles are also equipped with on-board tablet computers, which offer an interactive experience to the passenger. The tablets feature *Mellowcabs* own propriety software, which includes an augmented reality facility, geo-activation advertising, and full social media integration.

FIGURE 2.1: Second Edition Mellowcab Electric Vehicle (Ideso, 2015)

2.1.3. WHY MELLOWCABS?

Mellowcabs wants to reduce South Africa's dependency on cars, reduce traffic, and positively contribute to the South African transportation system. It is commonly known that Minibus Taxis are a problem, hence why *Mellowcabs* accepts the need for a social change and an over bridging alternative.

80% of all urban taxi trips are shorter than 3km, which is an extremely inefficient use of fuel burning engines, placing *Mellowcabs* in an ideal position to provide urban micro transport.

Carbon dioxide emissions are the greenhouse gasses that results from human activities and causes global warming and climate change. The concentration of carbon dioxide has risen to 400 ppm in May 2013.Fossil-fuel burning vehicles are some of the biggest polluters of our time. *Mellowcabs* provide completely emissions free, electric transport. The vehicles are made from recycled materials, are very efficient to run, require very little maintenance, and are fully electric. There is no fuel costs involved. Therefore, transport could be significantly cheaper than large fuel-burning vehicles.

The Mellowcab vehicles have gone through extensive roadworthy testing, and comply with United Nations roadworthy standards. Hence, they can operate legally on any road, making them a safe and efficient quality mode of transport.

Mellowcabs aims to provide a form of transport wherein South Africans (and Africans) from all walks of life will find substantial benefit. They aim to construct and operate at least one *Mellowcabs* charging station that makes use of renewable energy sources, such as solar or wind power, every 12 months.

2.1.4. DISRUPTIVE TECHNOLOGY AND ITS ROLE IN DEFINING THE TARGET CONSUMER

Major global trends such as urbanisation and the emergence of a younger generation with changing views regarding mobility, has seen the traditional view of the car as status symbol diminish (Selhofer et al., 2012:8; Chia, 2014).

This is predicted to have a disruptive impact on the way vehicles are used; car-sharing, door-to-door, rental etc. are becoming more attractive as commuting distances are reduced and public transportation is improved. Together with ever diminishing parking space, owning your own vehicle is becoming a less attractive proposition. Current vehicles are designed to cater for many eventualities. They are not optimised in terms of their design to operate efficiently within cities; e.g. studies show that predominantly only 1 to 2 people tend to be seated in one car, while the many accessories and large storage spaces are rarely used (Perterer, Martin, Lochner, 2014:674).

As is stated by Selhofer et al. (2012:47), "Mobility is becoming a service independent from means of transportation". This is a trend best recognised in younger generation where recent data by the Department for Transport in the UK, as well as a study implicating Norway and Sweden show; where a diminishing number of young people are likely to hold full drivers licenses. This effect is amplified in urban regions. Another Macro-Environmental factor, especially in Europe and the USA, is consumer awareness of climate challenges where, "The ecological footprint of products and services becomes an important feature for consumer choices – including consumers from mainstream lifestyles." (Selhofer et al., 2012:49)

User profiles for single owner MMV's such as the *Renault Twizzy*; which parallels more closely the design considerations for commuter MMV's than traditional vehicles also show similar trends. A study done by Renault to determine how people perceived the *Twizzy* MMV was conducted in Milan; considered "a trend setter city in which fashion is a relevant factor that plays a fundamental role in the daily routine". Almost three quarter of participants responded positively to whether or not they would purchase an EV. It is highly important to note that as the *Mellowcabs* is not a single owner or operator vehicle, but instead a commuter vehicle; not all the profiles that suit the *Twizzy* will fit the *Mellowcabs* target consumer. Relevant profile are categorised as The New Yorker (age 13), the Practical (age 30), the Liberal Egalitarian (age 31), the Activist (age 32) and the Post Modern individual (age 42), the full descriptions of which can be found in the appendix (Di Salvo, 2012).

Even though the above points to a shift in target consumer, it is not to say that attributes important to the mainstream should be ignored , e.g. a recent Frost and Sullivan global mobility study consisting of 5000 individuals show people still prefer to travel using their own privately owned vehicle (Govindarajan, Kopalle, Danneels, 2011:123) (Shankar, 2012). Factors such as comfort, private space, the convenience of door-to-door travel and the speed relative to some public transport services are cited as predominant reasons.

Understanding which aspects keep consumers out of MMV and in traditional vehicles should be considered as a first step in the design process of the side-door. This is necessary to avoid infringing on these aspects in a negative manner; instead any proposed door system should attempt to complement them.

The ambient environment for example, has been shown to play an important role in the perception of well-being and sense of relaxation, a crucial part of this being an occupant's perception of space inside a vehicle. Parameters that can greatly influence this include base vehicle geometry and dimensions, light exposure, ambient lights, colours and material selection. Research in the development of traditional vehicle cabin design has also shown, that in order to minimize occupant stress and optimize comfort and assuredness, it is important to optimise all areas directly interacted with by the vehicle occupant (Hiamtoe, Steinhardt, Köhler, Bengler, 2012:252).

2.1.5. OCCUPANT PERCEPTION

The *Mellowcabs* MMV occupants will receive and respond to a new side-door that depends not just on the feature set, but also on less concrete aspects such as simplicity of use, quality, trendiness, accessibility and design (Islam, Ozcan, 2012:36).

Helping to elucidate the relationship between the user and side-door system will be of utmost importance in creating a product that will be accepted by the occupant. The concepts of product affordance and product semantics capture well the relationship and communication that takes place between the two.

Distinguishing between the side-door semantic properties and affordances are crucial as both speak to differing aspects relating to the same design elements. Product semantics focuses on understanding how design attributes can illicit certain emotional responses from the user within a given context. If one attempts instilling a sense of quality and safety in a product it is important to understand that all products make a statement through their shape, form, colour, texture etc.

Affordances relate more to how physical properties of a design communicate its function to the user. Here aspects such as the human-sensory system, ergonomics and anthropometrics play a bigger role (Kannengiesser, Gero, 2011).

Whichever means of side-door design is decided upon needs to be optimised in terms of the above to project a sense of quality and safety. The qualitative nature of human perception complicates measurement, however subjective evaluation can be carried out as depicted in the case study of the *e-bike* Hiamtoe et.al, 2012:252).

2.1.6. CASE STUDY 1: THE CASE OF THE PORTABLE DIGITAL MUSIC PLAYER

As has been stated, the design process can benefit from having a mixed user orientation; including the traditional customer base as well as the emergent one (Govindarajan et al., 2011:131)

The *Apple iPod* for example is a product that upset the market through, as Islam and Ozcan, (2012:28) phrase it; "… fundamentally altering the way customers think about product performance because it exceeds their expectation in an unexpected way." It appealed to an emerging market through exceeding the performance expectations of products and services in the existing consumer market. It created new value beyond what the existing consumer demanded or knew it would want without the traditionally hypothesised pitfalls (lack of product resolution/quality) of disruptive products (Govindarajan et al., 2011:123) In this manner it could satisfy both existing and emergent customers. The framework applied in the development of this product, Kim and Mauborgne's (2005) Blue Ocean Strategy (BOS), allowed Apple to instil qualities which satisfy emerging and current consumers alike (Islam,Ozcan, 2012:28).

According to Islam, Ozcan (2012:28) "Innovations resulting from disruptive technologies usually offer change either in products or in services that are typically simpler, more efficient, easy to use versions of existing products or services already in the market".

In the book, 'The Innovators Dilemma', Christensen makes an important distinction between sustaining and disruptive innovation. Businesses practicing the former merely attempt to ensure their market position by developing existing products according to customer expectation. The latter fundamentally alters the way the user interacts with a product, creating new value beyond their expectation (Islam,Ozcan, 2012:28).

The BOS framework used to develop the *iPod* relies on two strategies. The first, the Strategy Canvas, is the central frameworks for evaluating what the current value offered to the users are. It depicts the competitor level on the horizontal axis, while the various features and value adding aspects are represented on the vertical (Figure 2.2). The benefits of utilising such a strategy are twofold. It determines on which levels competitors challenge each other in the existing market by considering key values and features offered. Additionally it helps companies define dormant gaps that can be seized upon (Islam,Ozcan, 2012:31).

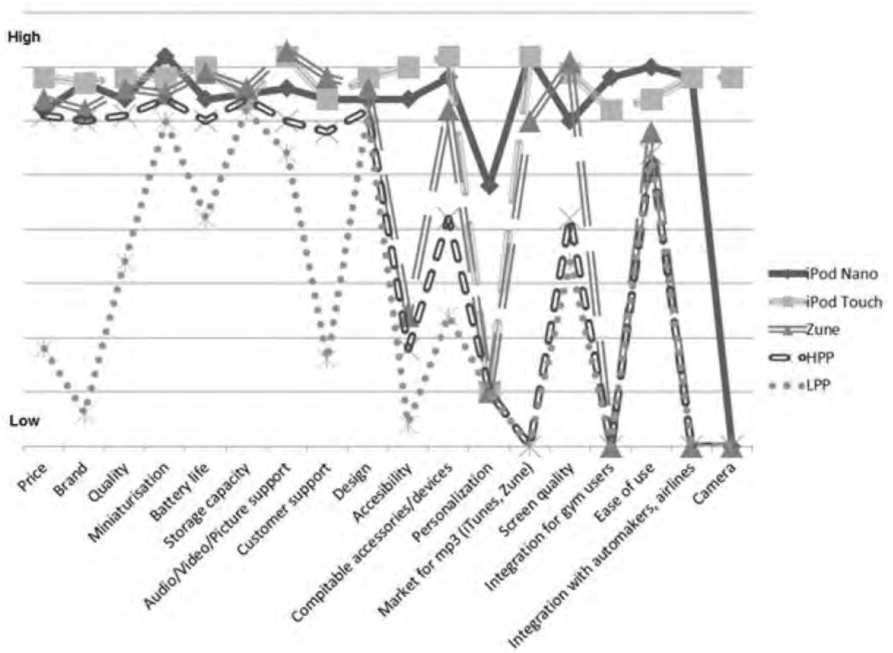


FIGURE 2.2: Disruptive product innovation strategy: The case of portable digital music player (ISLAM, OZCAN, 2012:31)

The second is a Four-Action-Framework (FAF) helps develop a new value curve through reimagining feature sets and value added features compared to the competition. Four basic questions need to be asked when applying this framework (Figure 2.3).

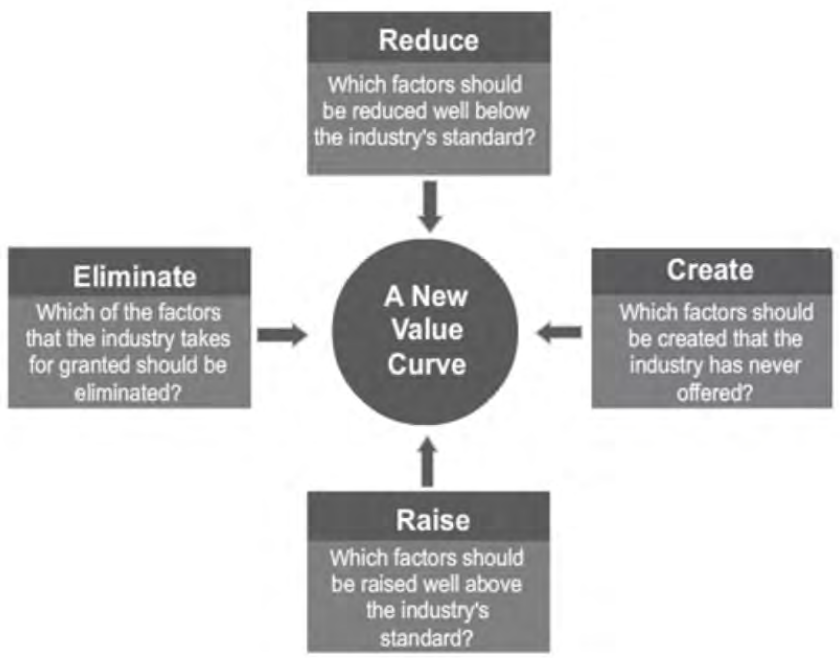


FIGURE 2.3: Disruptive product innovation strategy: The case of portable digital music player (ISLAM, OZCAN, 2012:32)

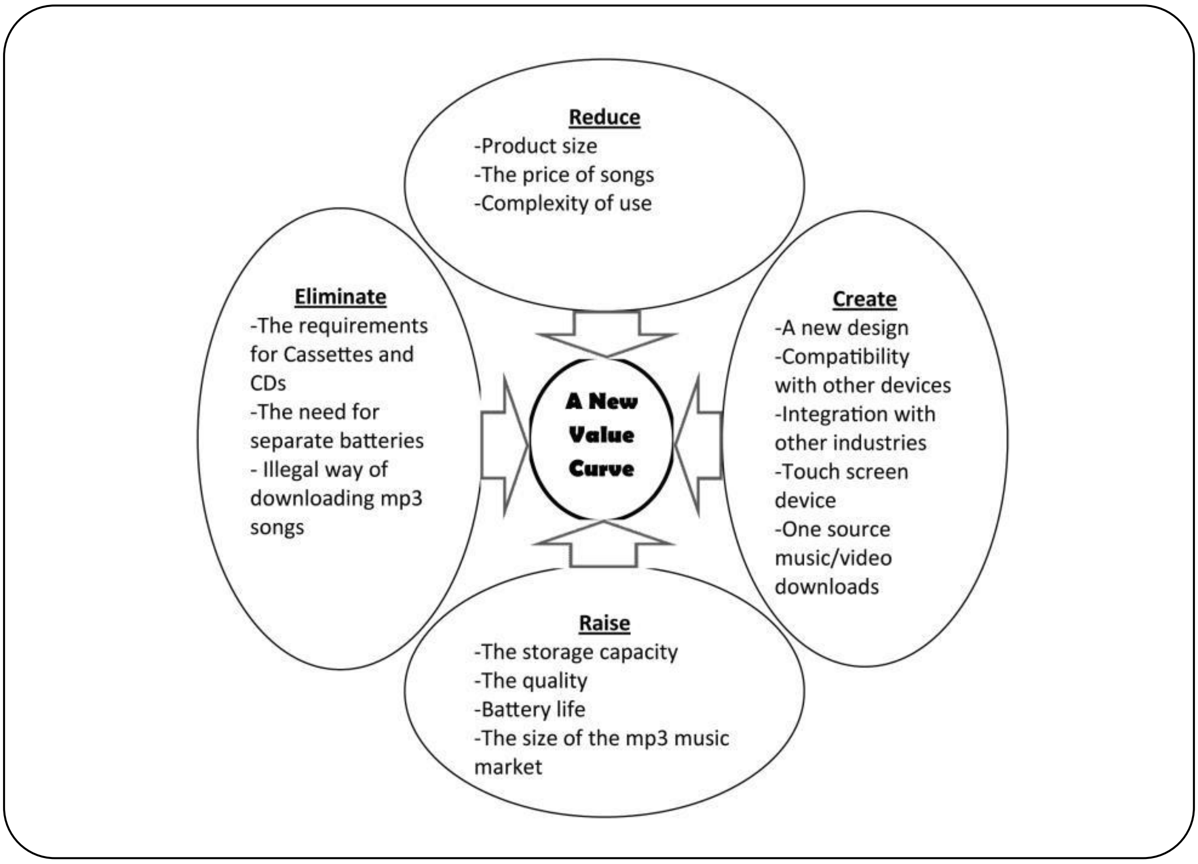


FIGURE 2.4: Disruptive product innovation strategy: The case of portable digital music player (ISLAM, OZCAN, 2012:32)

Simplicity, Convenience and Image

As can be seen, the *iPod* relies heavily on design driven innovation. *Apple* focuses heavily on how the product is perceived and performs as a whole; successfully integrating complex function and presenting it in a simple manner. In his book, *Laws of Simplicity*, John Maeda describes the *iPod* and the *Google* web browser as '*the epitome of simplicity in their design.'* One highly underrated aspect in developing innovative products is the aspect of convenience; where it is imperative for the new offering to perform in a more seamless and convenient manner (Islam, Ozcan, 2012:39). A key aspect to the design of the *iPod* is it fun image; which is generally perceived as trendy. In 2011 this led apple to become the world's most valuable brand, beating out brands such as Google into second place; elucidating how their products are valued by the customer. It also illustrates that it is not necessary to invent new technology to be a disruptive innovator, neither is it required by the user (Islam, Ozcan, 2012:40; Govindarajan et al., 2011:123).

2.1.7. CASE STUDY 2: THE CASE OF THE E-BIKE

The case study of the *e-bike* utilises the framework created by Feijs and Frithjof (2005) to evaluate how product semantics can be formally incorporated into the design process.

Within this framework 'semantic fields' that are grouped into three levels exist. These layers are interdependent, with the higher layers dependant on the lower ones. The higher layers can only convey proper meaning if the lower layers are clearly resolved. The various layers are given by Feijs and Frithjof (2005) in the figure below (Figure 2.5).

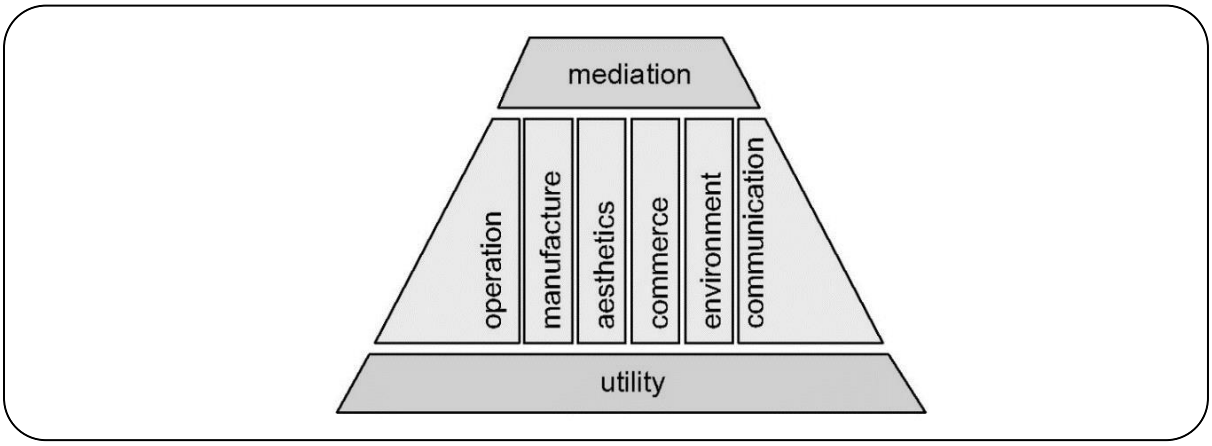


FIGURE 2.5: A formal approach to product semantics with an application to sustainable design (FEIJS, FRITHJOF, 2005)

- Utility represent the basic function of the product
- The intermediate layers are the extended functions the product requires to be successful and operational.
- Mediation – In this function the product is used to send a message about something other than the actual product – What Krippendorff (1989:67) would characterise as the products meaning.

Utility defines the product through its power, size, range etc. The ***Operations*** function includes the user product interface for physical and cognitive action; an area of great focus for this paper. This is an area where product affordances play a role in guiding user action. ***Manufacture*** includes areas such as mechanical structure, materials and technology used. It also visualises design tools and system integration. ***Aesthetics*** focus on subjective design elements such as shape, colour and proportions (Feijs, Frithjof, 2005:72). ***Commerce*** points to all the features that entice consumers to buy the product. The ***Environmental*** function sums up the effect all the underlying functions will have in terms of resource consumption and various levels of pollution; the products ecological foot print. If a product is well designed it will be self-explanatory and not need additional functions to do so; thus the ***Communication*** function should be an early indicator of how well resolved the design is (Feijs, Frithjof, 2005:73). The ***Mediation*** function is used to send a message. In the case of the electric bicycle the product attempts to send a message both about the user and sustainable development. As can be seen, the better resolved the lower product functions are the less artificial mediation is necessary.

The main aim in developing the *'e-bike'* was to give electrically supported bicycle their own identity as alternatives to traditional vehicles for urban commuting (Feijs, Frithjof, 2005:74). Feijs and Frithjof (2005:74) utilises the above semantic fields to conduct a formal analysis of the vehicles semantics.

Levels of meaning are first ascribed to each function in a bottom up manner; starting with the individual features of the bicycle until we reach that of a full product, at which point the meaning of the bicycle as a whole can be described (Feijs, Frithjof, 2005:76).

At the ***Utility*** level the bicycle has what can be described as '*features';* technical details, style elements, differing material, or construction elements that are easy to identify. These act as signs. Each sign sends a simple message; typically a direct technical, economic, or ergonomic consequence of the *feature*. The consequences of which can be grouped according the function, i.e. ***Utility, Operations, Manufacture,*** etc. The combined effect of that grouping is a message about the function itself (Feijs, Frithjof, 2005:76).

As an example; to determine the message sent by the ***Utility*** function one can analyse the seat. It is manufactured from foam, covered in leather and is anthropocentrically shaped. The message each *sign* sends is as follows: Foam - absorbent & compressible, Leather – soft, Anthropocentric shape - equal pressure and form fitting.

The consequences of all these features can thus be grouped as *'comfortable*'. As the combined effect of this grouping is a message about the function itself, the message the basic function (***Utility***) of the seat sends is that of comfort.

It is also worth noting that if there are multiple consequences for one product function, the combined effect must be considered (Feijs, Frithjof, 2005:76).

Figure 2.6 shows the product functions for the *e-bike* as well the messages they transfer to the users.

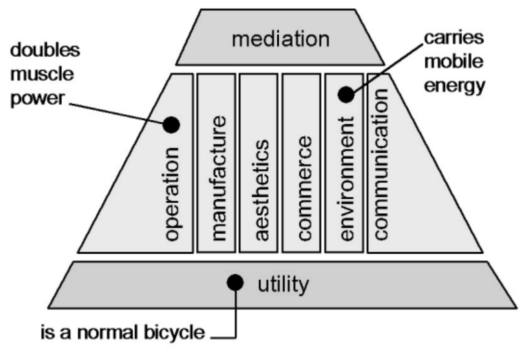


FIGURE 2.6: A formal approach to product semantics with an application to sustainable design (FEIJS, FRITHJOF, 2005)

According to Feijs and Frithjof (2005:78) the overall message the *e-bike* ***Mediates*** about the user is that of sportsmanship when compared to other such vehicles**.** "The message is told by the attractive balance in the bicycle's form. The message is also conveyed by the fact that the electric bicycle doubles muscle power (the user still has to work the pedal). Concerning sustainable development, it is statements that attractive electric bicycles can be developed that don't make the user appear weak" (Feijs, Frithjof, 2005:78).

The above mapping is also used to codify electric bicycle features compared to other such vehicles (Table 2.2).

First the accumulator is compared to the power transmitting devices of other personal mobility-vehicles because of the position it occupies; which is an area usually reserved for engines, gear-trains, brakes, etc. The message sent by not-covering mechanicals in a traditional bicycle is that the user is sportsmanlike; although the opposite applies for combustion engines, where a small combustion engine can convey the sense that the user lacks the power to 'drive' the vehicle themselves. This bodes well for the *e-bike* as the e-motor is already well integrated into the wheel hub. Although the internals of the accumulator are not visible, the accumulator itself is not hidden; Feijs and Frithjof (2005:778) deems it quite distinctive from the other signs.

Another feature comparison is that of luggage space which can be seen in (Table 2.3).

Sign (visual)	**(textual)**	**Meaning**
	Freewheel and derailleur	This is a bicycle with changeable gear-ration, showing technicalities.
	Chain cover	This is a normal bicycle, hiding technicalities
	Combustion engine	This bicycle has a moped engine
	Electromotor	This bicycle has an electromotor
	Changeable accumulator package	This bicycle carries mobile energy

TABLE 2.2: Disruptive product innovation strategy: the case of portable digital music player (ISLAM , OZCAN, 2012:31)

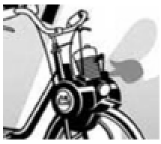
Sign (visual)	(textual)	Meaning
	Normal luggage space (front)	This is a normal bicycle
	Engine near front wheel	This bicycle has a small auxiliary motor above the front wheel
	Normal luggage space (rear)	This is a normal bicycle
	Tank near rear wheel	This bicycle has some unavoidable space-consuming storage device

TABLE 2.3: A formal approach to product semantics with an application to sustainable design (FEIJS, FRITHJOF, 2005)

2.1.8. SUMMARY

As is stated by Feijs and Frithjof (2005) “Product semantics is essential in the design of products that must be easy, safe, efficient, and pleasurable to use.”

Ideally a product should be easily recognizable for what it is, understandable in the way it operates and amenable to the users way of doing things. Krippendorff (1989:8) suggest that, “Product semantics seek to reduce this mismatch by suggesting self-evident and understandable interfaces”. The goal is to develop a product that the user can easily understand, as well as one that can accommodate a large range of possible cognitive models (ibid).

As the entire MMV platform is still unfolding and the above customers have limited experience with it, determining requirements and optimising the design can be difficult. Generally, quality of components could be the big factor since one who has experienced at least one part of defect in their vehicle will actually affect their judgement towards other factors in the vehicle. In the case of the side-door system there is assumed to be at least some historical experience with similar products, however very little in the context of this new format of vehicle. Due to the limited experience of the base product, in this case the MMV, it will be difficult for customers to articulate the needs in terms of the design of a side-door system, and thus participate in determining future requirements.

In the context of this thesis, Product Semantics allows for a body into which data from anthropometric, ergonomics, product and user trends can be integrated.

2.2. LITERATURE REVIEW

The Literature Review has its attention turned to the complicated simulation problem of vehicle ingress and egress. The wealth of data available from this research can serve as important guidelines for determining metrics for ingress and egress tasks. It also provides information about what should be avoided and what should be provided in an ideal design. In addition, some work has also been performed in the design and modelling of vehicles using virtual or semi-virtual experimentation. Thus, the following review section highlights that of: automotive ergonomics, which discusses vehicle- and occupant packaging; door design, which covers current trends for automotive door designs; effect on design, which covers functional adaptations to existing solutions; vehicle ingress and egress, which includes research in movement patterns for ingress and egress; and human factors digital modelling for virtual motion simulation.

2.2.1. AUTOMOTIVE ERGONOMICS

Automotive ergonomics is the study of how automotive vehicles can be designed better for human use. The human factor aspect of designing automobiles is first considered at the Vehicle Packaging stage. The term Vehicle Packaging comes to use whenever a new model is in the early stage of study. It is a method to safeguard and protect space for the human user and necessary components that make up the vehicle being designed.

The world Health Organization (WHO) attributes roughly 1.2 million deaths and 39 million injuries to traffic incidents each year. Vehicle design engineers aim to reduce these fatalities and injuries through the development of safer vehicles (Mohamed, Yusuff, 2007). This effort is supported by government regulations and consumer pull of safer vehicles, making occupant safety a key concern in automotive design. Vehicle occupant safety can be classified into two broad areas: the degree to which a vehicle protects its occupants in a crash, known as crashworthiness, and the extent to which the vehicle enables the driver to lower his or her chances of being in a crash, known as crash avoidance (Mohamed, Yusuff, 2007).

Vehicle Packaging in short is the organization of space for people and the parts of vehicle suite a specific need or transport. It is the first consideration for shaping the vehicle. During the vehicle package stage, factors such as engine size, weight, width, height, luggage, number of passengers, and their seating arrangements are targeted. Knowing all the said parameters plus more will help to establish a range of dimension within a category of vehicle types and cost, enabling the designer to target shape of vehicle on a "family of dimensions" that will make it competitive.

Vehicle Packaging actually dictated of how a vehicle should be designed. It provides all the necessary information for the styling designers and part designers to proceed with at the following stage. On the other hand, since Vehicle Packaging is meant to provide suitable space for people and parts in vehicles, human factor considerations are a must for the integration of the total design. In vehicle design, the term human factor is interchangeably called as automotive ergonomics (Roe, 1993).

Occupant packaging is the interior design process of a vehicle to achieve a good level of accommodation, comfort and safety for passengers. The most relevant to the ergonomics variables when considering occupant packaging are: interior dimensions (SAE J1100, Reaf. 1998), hand control reach (SAE J287, Reaf. 1998), and driver selected seat position (SAE J1517, Reaf. 1998).

In designing an automobile, there needs to be certain dimensions that have been agreed for by the management design, and manufacturing departments. As much as design aesthetics is important, so do the cost factor and manufacturing capability. Design has to be aligned with proper product positioning and budget as well as manufacturing line setup.

2.2.2. DOOR DESIGN

Doors are highly complex structures that contain just about everything that acts as a whole contains except for power train elements. Customers interact intimately with doors and are aware of them along many dimensions. Doors also comprise both interior and exterior elements causing them to be links between those domains of the car. Many of the attributes conflict; for example, better water leakage and wind noise behaviours will make it more difficult to close the door; better side intrusion protection will make the door heavier; better leakage around the glass makes it harder to raise the glass, requiring stronger motors, making the door heavier.

Mr. Will Boddie, then Vice President of North American Engineering, sought to improve door design by creating a new job title called Closures System Integrator (CSI) in the Engineering Department and Mr. Ver sought similar results by creating a new job title called Manufacturing System Integrator (MSI). The goal was to increase focus on door attributes that customers pay attention to, such as wind noise, water leakage, closing effort, and squeaks and rattles, and to coordinate design and manufacture of doors to achieve attribute targets with better time to market and lower variability (Baron, 2001).

The height of the door-sill affects the ease or difficulty in the phase of lifting ones legs in or out of the vehicle. The higher the sill the more strain the subject would have to exert to lift their feet over the sill. The door-sill should be well rounded and have a smooth surface with no sharp edges to permit people's feet to easily glide over. If the height of the door frame is too low, it would affect the subjects when entering and leaving because they would have to bend their necks to prevent hitting their heads on the edge of the roof (Mohamed, Yusuff, 2007). The angle to which the door opened should be approximately 70-degrees or sometimes 90-degrees. An angle of 70-degrees makes the space large enough to enable the passengers to lift their feet in and out and to rise. The door should be fitted with a mechanism that locks it in the open position; otherwise the door is not suitable as a support (Noor, 2007). Door design for better crashworthiness in case of a side impact and designing the door latch mechanism so that the door don't open when a crash happens and do not get locked after the crash is again a factor to be kept while designing.

The most common door which can be found in automotive market is the classic rotating door. It is the most common door used, it is well known to everyone because it opens like the typical door in a conventional house (Mohamed, Yusuff, 2007). Being very common, the assembly becomes fitting, cheap and also simple although it has a disadvantage because a huge lateral space is needed for its manipulation. The same disadvantage can be found in a gull wing door although this door makes easier the entrance as its opening is in the upper side of the car (Whitney, 2008).

Figure 2.7: Conventional rotating car door (Author, 2015)

To continue, the scissor door should be mentioned as a very similar kind of door. This one has also a vertical opening and it is fixed in the area near the end of the windshield. Its look is very pleasing but it needs a considerable height to work properly.

Figure 2.8: Scissor car door (Boeriu, 2016)

The suicide door is opened by the opposite direction to the conventional. It is hinged on the trailing edge. Additionally, the edge is closer to the rear of the vehicle. As a result, the space is very limited between the front edge of the rear and the rear edge of the front door and it is also more dangerous than any other door due to its special way of being opened (Whitney, 2008).

Figure 2.9: Suicide car door (Author, 2015)

The doom door or gullwing door is placed in the top of the car and it can be opened by many different ways. The hinges can be placed on the front, side or back. It provides an aesthetically pleasing look but it has a great complex and expensive system (Mohamed, Yusuff, 2007).

Figure 2.10: Gullwing car door (Pollard, 2015)

The sliding door in the car world is opened by sliding out on rails so that small lateral space is needed for its handling. Moreover common sliding door concepts do not fit to sportive passenger cars from the design point of view (Whitney).

Figure 2.11: Sliding car door (Carponents, 2016)

The disappearing door works by using a window lift button to be opened and closed. In this way, the door goes inside the bodywork of the car. The best characteristic of this concept is that no space is needed but an ordinary customer cannot afford it because it is extremely expensive, as the system becomes deeply complex (Baron, 2001). An easy and cheap construction system is one which consists of slides where the door is placed on rails located on the bodywork. But, in this case the bodywork must be changed, taking into account that the space is limited by the rear wheel (Whitney, 2008).

Figure 2.12: Disappearing car door (Jansen, 2008)

All these door kinematics have in common that they only employ one degree of freedom (DOF) and hence can conduct only one predetermined door moment. They cannot react to different ambient situations. For the evaluation of car doors to allow ergonomic ingress and egress, simulation tools can be used for reach ability design. In order to improve the design of the car body the influence of the vehicle geometries, such as the door sill height or A-pillar angle, need to be analysed (Baron, 2001).

2.2.3 EFFECTS ON DESIGN

Functional Adaptations – Existing Solutions

As MMV design is a fairly new area, few commercially available examples exist; however those that do can be evaluated in relation to their performance in inclement weather. The previous sections have made it clear that it is in the best interest of usability and comfort to keep the commuter dry and free from sudden temperature changes. Various examples for both vehicular and physical weather protection exist and will be discussed below.

Many touring motorcycles and some specialised scooters are available with factory or aftermarket extended screen protectors; a market where riders will not consider a vehicle without good wind protection as it can have adverse effects on hearing and comfort. Even at the relatively low speeds the *Mellowcab* is capable of wind noise can become uncomfortable.

Wind entering the cabin also exposes ears, hands or any other parts of the body to rapid cooling; causing discomfort (Industrial Paramedic Service, 2005). Utilising the base BMW C1 mentioned in the introductory section of this literature review we can look at various additional adaptations available to limit the effects of wind and rain. *Windkits* are highly popular amongst BMW C1 owners, and have been the topic of discussion on many occasions spanning over 10 years (The UK C1 Forum, 2015).

Figure 2.13: Aftermarket BMW C1 Wind Deflector Kit (Verigo, 2008)

Figure 2.14: Mesh Wind Deflector (Databikes.com, 2015)

Many feel they make a considerable contribution towards reducing noise and protecting the neck and general upper body region from wind. These kits have also proven to be successful at reducing the amount of rain riders are exposed to (princeharry, 2004) (gxprice, 2012). They however still require some protective gear such as waterproof trousers, gloves and sufficiently insulated clothing to guard against the wind and rain that does make it into the cabin (jervanheg, 2003).

For additional warmth some riders adopt seat warmers or waterproof leg covers; an accessory that is available for many scooters on the market. Highly popular and effective at keeping riders warm and dry, these covers are attached to vehicle via a series of straps that can run either under or over the vehicle, or be solidly attached with fasteners. To cut down on water leakages and retain hot air underneath, they are custom designed to match specific vehicle models. Lined with faux fur and high visibility stitching; these covers are also fitted with bladders that can be inflated to reduced flapping in at speed (UrbanRider, 2009).

Figure 2.15: BMW C1 Leg Cover (Scootech, 2015)

A more elegant solution is proposed by the Renault Twizy. Launching without any side protection like most commercial and concept MMV's; Renault adds the option of detachable side doors. In addition to forward wind deflectors to achieve the same effect as the BMW C1 mentioned above, the Twizy's optional doors also provide full lower leg coverage. This not only protects occupants from wind ingress, but also reduces the likelihood of spray from other vehicles entering the cabin. These doors do not have windows, however as added extra in addition to the optional doors, Renault provides optional clip on side screen (Blingley, 2014).

Figure 2.16: Renault Twizzy fitted with door and window (Trustcar, 2014)

There are however some usability issues that limit the appeal of Renault's solutions. One has to first unzip the transparent window from its rigid metal frame to access the door handle on the inside of the vehicle as it does not have any exterior handles. As the Twizy's doors do not provide enough lateral movement when opening, the screen tucked under the curve of the vehicle's roof needs to be pushed free or tugged from the outside for the doors to open (Blingley, 2014).

The window frames are not designed to seal against the vehicle body; meaning water can stream in from the front and bottom. The protection however is sufficient to prevent water from soaking the passenger, even though the presence of all the leaking water could potentially lead to discomfort; passengers adopting behaviourally to avoid getting wet. In terms of ventilation however this does negate the need for complicated and expensive HVAC (Heat , Ventilation and Air Conditioning) systems; the Twizy having a heated screen in case any misting does occur (Blingley, 2014).

Figure 2.17: Hard to reach handle (Blingley, 2014)

As can be seen in figure 2.19 there is also a very large gap directly adjacent to the passenger seat; between the window, door, and vehicle body, potentially allowing rain and wind to enter the vehicle from the side.

Figure 2.18: Water Ingress (Blingley, 2014)

Figure 2.19: Large opening behind doors (Rix, 2013)

Figure 2.20: Roof rail susceptible to the Coanda-Effect (Tutu, 2012)

Given the research another issue can potentially arise with the vehicle itself – although the roof rail is shaped well for shedding water, rain coming from the side at an angle could attach to the underside of the rail. This can cause water to drip into the cabin due to the *coanda-effect.* As always some aftermarket alternatives exist, however these are also flimsy as well as cumbersome to use (Dehais, 2014).

2.2.4. VEHICLE INGRESS AND EGRESS

Ingress and egress are considered complex tasks due to the multitude of sensory and motor information necessary to access a vehicle. The ease of getting in and out of a car is one of the ergonomic issues that catch the attention of many car manufacturers. It represents the first physical contact of the customer with the car. Therefore, it is important to ensure pleasant sensation while accessing the car. Understanding how drivers and passengers move and interact with respect to a vehicle is very important to Vehicle Packaging design. Being able to assess a vehicle's ingress and egress performance early in a design process is therefore crucial to successful vehicle development.

The biggest difference between ingress and egress with a simple task like walking it that ingress and egress motion interacts with geometries. While a person could walk without any geometry, ingress and egress motion needs to have objects to get in and out of. During ingress and egress motion, a person cannot strike the objects. Each frame and individual components of the object would be an obstacle to avoid.

The prediction of human movement strategies for ingress and egress is a complex topic, but two observations are important here. First, strategy for ingress and egress is associated with both design variables and subject characteristics in an interactive way. Among the parameters influencing ingress and egress, the roof height the sill height and width are probably the most critical. Additionally, the door angle should also be considered in vehicle design to determine the optimal vehicle ingress and egress points that are associated with level of comfort.

The current design considerations for ingress and egress are as follow: Design features should be comfortable, design and placements should be safe, important controllers and components should be reachable and displays should be visible to the user, there should be no obstructions while getting in and out, and they should be usable by a wide range of the population.

Assessing ingress and egress patterns provides an important step in considering how vehicles can be better design to improve both comfort and safety. Most research was conducted in France (7 of 9), with others taking place in Germany and the United States. Several studies assessed kinematics using the Vicon system in conjunction with force plates and an H-point machine. Other studies imported postures into RAMSIS to develop aspects of a digital mock-up. A total of nine studies that examined vehicle ingress and egress of drivers were included in these methods. These studies varied with regard to the size of the sample, as well as the demographics of those whose motor patterns and perceptions were captured, including age, gender, height, and stature as well as corresponding differences in experimental design.

2.2.5. MOVEMENT PATTERNS DURING INGRESS AND EGRESS

Most drivers get into a car with the right leg first strategy (Chateauroux, 2009). The corresponding ingress motion can be divided into 4 phases. Firstly the driver gets the right foot inside the car while standing on the left foot only. Secondly, once the right foot is on the car floor, he/she transfers the body weight towards the seat while standing on both feet. Thirdly, once seated, the left foot gets into the car. Finally, he/she moves the body in the middle of the seat to adopt a driving posture.

For the egress, the left leg first strategy is the most commonly used. The motion can be divided in the 3 phases. Firstly, the driver moves the left foot out of the car while being seated. Secondly, one the left foot on the ground, he/she stands up with both feet being supported. In addition, the hands can help the weight transfer by pulling/pushing on the steering wheel. Finally, the right foot gets out while standing on the left foot.

Two studies examined ingress and egress across four different vehicle models: small and medium size vehicle, small commercial vehicle, and a minivan. Their studies included 41 participants: 8 young and healthy adults (Mean age 26 ± 5); 19 older adults (Mean age 71 ± 5); and, 14 adults with various disabilities (Mean age 62 ± 13). Based on these analyses, ingress patterns were categorized into three phases: 1) door opening phase, 2) ingress movement adaptation phase (i.e., lifting of left leg from ground into the vehicle) and 3) seat phase (once both legs reach the ground floor). Analysis of these phases specified five ingress movement strategies (i.e., lateral sliding, backward motion, forward motion, trunk forward, trunk backward) and three egress strategies (i.e., head forward, parallel, and two foot). Although no specific ingress and egress strategy was observed by sample composition (i.e., young and healthy versus elderly versus pathological), kinematic data showed that healthy older adults tended to use a lateral sliding and backward motion approach during ingress and egress compared to the younger and pathological participants (both young and old). Additionally, kinematic data showed that ingress and egress strategies (i.e., lateral sliding, forward and backward motion, trunk forward and backward motion, head forward, parallel to the vehicle and two-foot egress) were not influenced by vehicle geometries despite the considerable differences across the four vehicle types.

Building on these findings, another study examined ingress and egress motions in 7 younger (Mean age 26 ± 5) and 18 older participants (Mean age 71 ± 5) using the same four vehicle models as described in Menceur et al. (Monnier et al., 2006).According to their analysis, two primary egress strategies (instead of three) were identified: 1) left leg first and; 2) two legs out. However, the two legs out strategy were only used in 10% of cases (10 of 100 motions). Two older adults used this strategy across all four vehicle models when exiting vehicles (8 of 10 motions). The authors' postulated this egress strategy was linked to mobility, meaning those with balance problems required greater stability and, as such, were more likely to use the two foot out strategy.

In some cases, participants (mean age 33 ± 9; 14 men; 4 women) used their hands to help with both ingress and egress, which was found in more than 65% of observations. Hand contact with the steering wheel was commonly observed, however, there was no hand contact with the sill and door frame. During egress, kinematic data indicated maximum contact force between the hand and the steering wheel occurred when the left foot was in contact with the ground. This force decreased when the right foot was placed on the ground outside of the vehicle and the driver's weight transferred from the right to left foot when exiting the vehicle.

Eight studies constructed a vehicle mock-up to test ingress and egress. While the mock-up can be used as a proxy measure, none of these studies included a full layout of an actual vehicle. Validation of the vehicle mock-up with actual vehicles is critical to ensure the fidelity of an experimental set-up. A high fidelity mock-up is an important consideration where the influence of specific vehicle dimensions on ingress and egress patterns will be examined in future studies. Additionally, only five of the nine studies used an H-point machine. Future studies should consider including an H-point machine for identification of a vehicle's occupant hip joint centre, as this point can serve as a starting position for many design related decisions.

2.2.6. SAFETY FACTORS

Transitioning out of the cab onto slippery, greasy, or oily surfaces can also cause slips and falls. In winter weather, water, now and ice can accumulate on the path that leads in and out of the cab. Oil and grease, mud, snow can accumulate on yard surfaces and be transferred to the driver's and passengers shoes. Use of foot and handholds, as well as non-skid coating on the deck can help prevent falls. In addition, drivers and passengers are expected to maintain a "three-point stance" during cab ingress and egress. That is, they are expected to have two feet on the surface or structure and one hand on the handhold at all times. This stance should also be used when climbing in and out of the cab. Furthermore, the driver and passengers must be aware that jumping from and to cabs is dangerous.

2.2.7. HUMAN FACTORS MODELING AND VIRTUAL MOTION SIMULATION

A general trend in the design process is to reduce the total engineering development cost and time-to-market of a product by using computer aided-engineering technologies. In this context, car manufacturers use Digital Mock-ups together with Digital Human Models (DHM) to assess the ergonomics of their product during the early phases of its design. Integrating DHMs in the early design process allows the improvement of product and workplace ergonomic design through virtual simulation of physical interaction between target customers and the designed system.

In order to simulate the dynamic motion for ingress and egress effectively with respect to time and cost, some literature is reviewed. We can mention the motion simulation framework developed at the HumoSim, University of Michigan, USA (Reed, Huang, 2008), the leading body parts approach developed by BMW Group, Germany (Cherednichnenko et al., 2006), the RPx data-based motion simulation approach, developed at Renault and INRETS, France (Monnier et al., 2006), and the motion distribution map approach develop at the Digital Human Research Centre, AIST, Japan (Kawachi et al., 2005). Moreover, the French Ministry of research financed the “HANDIMAN” project. It aimed to better consider the needs of older and motor impaired people for car design and focused on the car ingress and egress motions.

The most common approach to generate motions or posture for a certain task is based on the experimental data that are statistically collected from a lot of motion captures. Motion capture technologies have also been used in vehicle design for various applications, such as vehicle seat belt usage, in-vehicle reach, and ingress and egress. However, human motions with respect to the use of a vehicle are constrained by various vehicle components, for example, seat, steering wheel, instrument panel, and door. For a complex motion such as ingress and egress motion, the human body itself causes obstruction as well. For more natural and realistic simulation, not only should the effects of anthropometry based on kinematics be investigated, but also the effect of dynamics aspects.

Parametric modelling makes use of parameters to define a model within a three dimensional space. Examples of parameters can be dimensions used to create features, material properties, algorithms, and formulae (Rossignac, Requicha, n.d). It is important to commence the design process in product lifecycle management software with a “wire frame” or “Skeleton Model”. This serves as the foundation or blueprint of the design and all design parameters and subsequent changes that take place later in the development should be constraint to this. This enables the designers and engineers the freedom to change parts and assembly constraints throughout the development process.

Parametric modelling can be a very powerful tool, but it requires skill and a thorough understanding of what the designed model is intended for, for example, will it be used for simulation purposes such as CFD (*Computational Fluid Dynamics*) and/or CAD/CAM systems (*Computer Aided Design/Computer Aided Manufacturing*) (Ault, Giola, n.d). These various aspects make it imperative for each member tasked with design, to not only have a good understanding of the parts/sub-assembly specifically pertaining to their respective disciplines, but also a concise knowledge of the product as a whole.

Simulation of ingress and egress using digital human models has three major objectives. First, visualization of ingress and egress behaviours can be used to illustrate design issues identified by other means. Second, a human-model-based analysis could be used to differentiate alternative designs with respect to safety through biomechanical analysis. Third, human models could be used to predict subjective responses to the ingress and egress experience in passenger vehicles.

When incorporating a manikin in a virtual environment, it is essential that the correct anthropometric data is captured by the software. Customising said data can enable the engineers and designers to design for specific percentile range. The position of the H-Point or centre of gravity can be used as a reference to ensure that the manikin is parametrically constrained to the main assembly. This allows for ease of movement in the main assembly, as the manikin's position can be altered by a parametric formula.

The ability to assign certain tasks to the manikin and subsequent simulations can inform the design process to a large extent. Important aspects such as ingress and egress can therefore be assessed to a good degree of accuracy. *Dassault Systeme's (DS) CATIA V6*implements the manikin as a sub assembly within the main assembly. This means that the manikin has its own set of customisable attributes with biomechanical kinematics mimicking that of a human being. The data proffered from virtual simulations will be compared to that of physical results to evaluate the accuracy.

By utilizing parametric CAD software it is possible to predict the outcome of various human factors, such as ingress and egress motion related issues without having to physically create prototypes or apparatuses. By investigating the attributes of a manikin in a given virtual environment (3D space), designers and engineers can generate a better understanding of the constraints and needs of the occupant.

2.2.8. SUMMARY

To sum up previous sections, understanding the characteristics of ingress and egress is important for this thesis. The biggest difference between ingress and egress with a simple task like walking is that ingress and egress motion interacts with geometries. While a person could walk without any geometry, ingress and egress motion needs to have an object to get in and out of. During ingress and egress motion, a person cannot strike the objects. Each frame and individual component of the object would be an obstacle to avoid. Therefore, collision avoidance should be imposed at the proper time on the proper object.

Additionally, quality of components could be the big deciding factor, since one who has experienced at least one part of defect in their vehicle will actually affect their judgement towards other factors in the vehicle. So measurement and evaluation will give a better understanding of how packaging of vehicle interiors contributes to automotive ergonomics.

When incorporating human factors in a virtual environment, it is essential that the correct anthropometric data is captured by the software. Important aspects such as ingress and egress can therefore be assessed to a good degree of accuracy by utilizing parametric CAD software without having to physically create prototypes.

In the context of this thesis, factors to consider are passenger view (inside and outside), door entry and exit, rear passenger clearance and spaciousness, vibration and noise, and trunk space.

CHAPTER 3

3.0. RESEARCH METHODOLOGY

This thesis primarily follows the methodology of a Participatory Action Research (PAR) Approach, which is the best fit to inform and drive the design development process and the movement analysis. It will follow a hybrid of design and research lead perspectives that will employ knowledge from ergonomics, anthropometrics and sociology, as well as feedback from various PAR research methods (Sanders, 2002).

This chapter lays out how the author has gone about first identifying and then exploring areas relevant to the main research question. Participatory Action Research (PAR) methods are inherently flexible, which has allowed for restriction brought upon testing via various factors such as vehicle availability, state of functioning, and variable weather. The following methods were employed to gather both qualitative and quantitative information through primary and secondary research. Data analysis of the results can be found in Chapter4: *Findings and Results.*

The use of CAD software with regards to human factors applications will be utilized to simulate in-vehicle scenarios. Inserting anthropometric data and assigning tasks to virtual manikins with the use of Human Builder CAD software can simulate the way certain percentiles will perform in certain environments or situations.

3.1. RESEARCH DESIGN

The Research Design section describes the proposed approaches, intended steps and methods of the study employed to gather both qualitative and quantitative information through primary and secondary research towards the development of a virtual model to evaluate the ingress and egress motion posture analysis and for the design of a new side-door concept of a MMV.

3.1.1. UNSTRUCTURED INTERVIEWS

The use of full names and information presented below was done with the full permission of participants.

The *Mellowcabs* MMV door development design project and virtual motion analysis is under the design supervision of the *PLMCC* (Product Lifecycle Management Competency Centre). The *PLMCC* is a centre that trains students, technicians, technologists, engineers and industrial designers in the art of product design and product lifecycle management (PLM). Located at the Cape Peninsula University of Technology (CPUT), in its Engineering Faculty, hosts and supervises numerous projects from different departments within *CPUT*, e.g. design of the Formula Student electric racing car, design of the Shell Eco Marathon urban concept car, Solar Water Heater project, Low Cost Wind Turbine project and the one handed Food Preparation Aid.

Therefore candidates from within the *PLMCC* are identified to create a collective focus group or team, which will centrally focus on the research problem at hand. The team consists of Mechanical-Engineers, Electronic-Engineers, Project Managers, Technicians and Industrial Designers.

Exploring the initial hypotheses, it first had to be determined to which extent vehicle usability might be hampered by adverse weather. Quantitative and qualitative information needed to explore this was gathered in discussion with *Mellowcabs* CEO Neil du Preez. Initial feedback in terms of vehicle performance and limitations were garnered. The effects of vehicle design in the context of expansion into global markets were also discussed both in terms of regulations, classifications and laws. A summary of the above discussions can be found in Chapter 4, *Subsection 4.1.1 Unstructured Interviews.*

Various discussions were also held with Industrial Designer Naeem Cassim whom has aided in the refinement of the requirements for the MMV side-door system to allow for a solid starting point from which concepts and prototypes can start to generate. Discussions within these sessions should highlight problems and introduce design solutions. With regards to this paper, focus groups will be held on a monthly basis at the *PLMCC* premises.

Utilising this information as a base, later usability testing was set up to quantitatively and qualitatively evaluate user's performance in real world testing. This was done to determine if indeed usability remained unencumbered as modelled, and if not, whether it posed a greater deterrent to vehicle adoption than possible weather related issues. An informal interview with Christopher Hendrikse (an Avid motor cycle rider and cyclist) was also conducted to gain feedback in regards to 'open sided' riding in adverse conditions.

3.1.2. VIDEO ANALYSIS

To allow for quantitative data collection during usability testing, video analysis of various actions performed by participants were tracked via video. Throughout the process ingress and egress processes were timed and analysed. Qualitative data as regards to posture, perceived sense of comfort and participant behaviour were also analysed. The observation had mostly focus on how to move from or to the interior of the vehicle while avoiding obstacles. Key components were presented and determined as obstacles to avoid. The movement and direction of the body was also tracked in the vehicle geometry. Through this process, ingress and egress movements was analysed in chronological phases. These video analysis observations will generate a description for the ingress and egress motions of the MMV, and moreover serve as a referencing sample for the generation of the digital human models in the virtual simulation process.

These results can be found in Chapter 4, *Section 4.1.2 Usability Test & Video Analysis.*

3.1.3. USABILITY STUDY

A usability test was conducted with the aim of establishing whether or not there was any truth to the initial hypothesis, and if so, whether commuters deemed it as the primary concern affecting vehicle usability. Simulated 'Follow the Object' testing was conducted to mimic specific environmental scenarios related to an urban context (Innovationenglish, 2015).

Participants were also encouraged to utilise the 'talk as you go' method when appropriate to collect qualitative feedback (Rubin & Chisnell, 2008).Tests were done simulating dry, wet and dark conditions. To accumulate representative data, the wet simulation was conducted from anywhere between 1 and 4 minutes. Testing in regards to low light was also conducted using special glasses to simulate reduced visibility. Additionally, testing to measure ingress and egress in tight spaces was also conducted (The layout of this test can be found in Appendix A).

The sample size consisted of five individuals both male and female and included:

- ***Participant A – Female, 23, Medium build, Medium height***
- ***Participant B – Male, 23, Muscular build, Medium height***
- ***Participant C – Male, 34, Medium build, Tall***
- ***Participant D – Male, 26, Slim build, Medium height***
- ***Participant E – Male, 31, Large, Short***

As testing included risk of exposure and injury, each participant was asked to complete a form of consent. A copy of which can be found in Appendix B.

3.1.4. QUESTIONNAIRES

To garner further qualitative information regarding expectations and perceptions, questionnaires were completed after each section. A copy of the forms can be found in Appendix M & N).

3.1.5. MOVEMENT ANALYSIS

Certain factors should be considered for generating the ingress and egress motion of passengers for MMV's. Therefore, and to simplify the process of modelling and simulating the motion for a digital manikin, the movements of participants were observed and analysed, then divided into two smaller independent tasks: ingress and egress.

TASK SUBDIVISION

For continuity of the motion for ingress and egress, the ending position of each subtask should be identical to the next starting position. The ingress manoeuvre is again divided into two subtasks: entering the cab and sitting. The egress manoeuvre is again divided into two subtasks: rising and exiting the cab. The key frames for each subtask are summarized below.

<u>Subtask 1 – Entering</u>
Since opening the door will not be considered in this subtask, the starting position should be the standing posture. Therefore, Subtask 1 starts from a standing posture and ends in a sit-ready position in the cab.

<u>Subtask 2 – Sitting</u>
This is the position in which a passenger fits his body in a narrow area between the front driver seat and the back seat. The hip should be located in the proper area of the seat.

<u>Subtask 3 – Rising</u>
This is the position in which the passenger gets up and prepares to move out. The hip should be off the seat while grasping the safety bar.

Subtask 4 – Exiting

This is the position in which the passenger steps out while exiting the cab. The passenger rotates his body to face the exit of the cab.

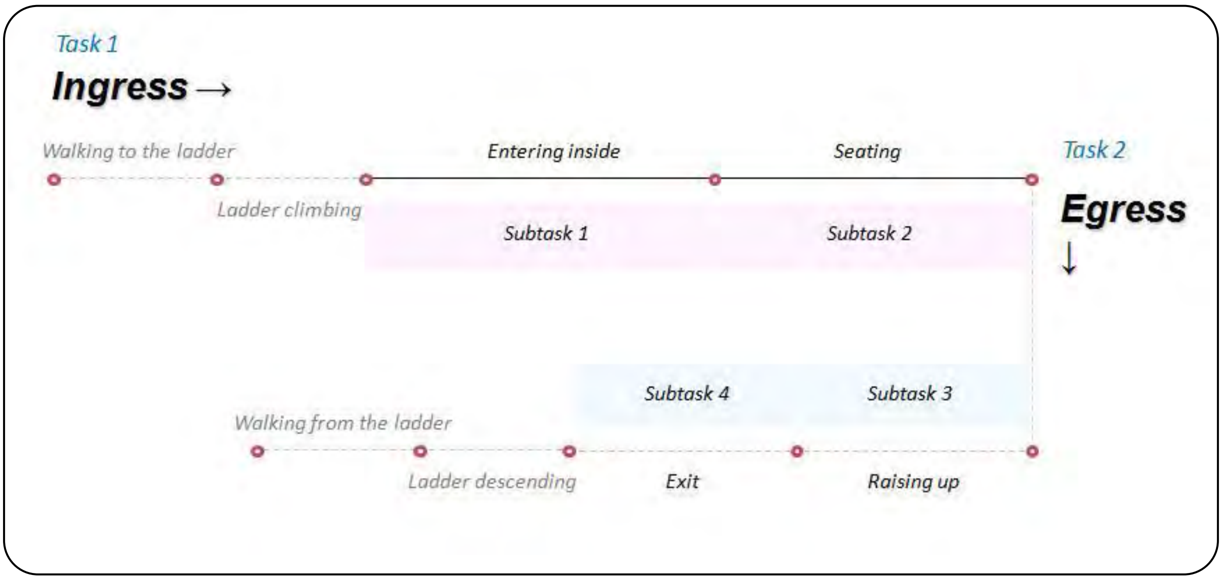


FIGURE 3.1: Task Subdivision for Ingress and Egress

KEY COMPONENTS

Key components are determined by video analysis. When the passenger gets in through the door frame, it becomes a key component to avoid. The arms cannot penetrate the frames and the foot cannot go through the step; the passenger has to bend to avoid hitting his head on the top side of the frame. While moving in and out of the narrow seat area, the lower body should avoid both the driver- and passenger seats. Therefore, the seat is defined as another key component. The key components are provided to the ingress and egress model which represented by the cab geometry of the *Second Edition Mellowcab Electric Vehicle*.

FOOT POSITION INPUTS

Foot position are defined by the size of the passenger foot, passenger seat, the location of the door, the height of the cab floor and the width of the space the manikin can move in. Foot positions are determined by ingress and egress movement analysis in section 3.1.5.; then given directly to the manikin in the stipulated cab geometry.

HAND POSITION INPUTS

To adhere to the three points of contact safety regulations in Section 2.2.6., the passenger must grab something for their safety while moving into the cab. In order to satisfy this condition, the user has to specify hand location as an input. Hand positions are determined by ingress and egress movement analysis. Hand position itself were predicted and analyzed during the movement analysis in section 3.1.5.; then given directly to the manikin in the stipulated cab geometry.

3.1.6. MATHEMATICAL MODELLING

Wind Tunnel Simulation data were checked to corroborate secondary research relating to moving vehicles.

3.1.7. EXISTING DESIGN EVALUATION

Two case studies analysing the effectiveness of various solutions were done. The first relating to commuter protection of a two wheeled open sided petrol powered vehicle (BMW C1); the second a four wheeled electric MMV fitted with optional Original Equipment Manufacturer (OEM) doors (Renault Twizy).

3.1.8. VIRTUAL HUMAN FACTOR SIMULATION

This section describes the development of a virtual human model or manikin to perform ingress and egress motion for MMV's. In this context, the use of digital mock-ups together with digital human models (DHM), is to reduce the total engineering and design development cost and time to market of a product by assessing the ergonomics through virtual simulation of the physical interaction between a user and the product.

Therefore regarding the virtual human factors simulation for a micro-mobility vehicle, this section describes the digital model of the cab geometry, as well as the digital human model that will perform the ingress egress movement within this geometry.

CAB GEOMETRY MODEL

This digital cab geometry model takes on the size and shape of a generic *Second Edition Mellowcab Electric Vehicle* and consists of the key components determined by the video analysis of the *First Edition Mellowcab Pedicab*. The model demonstrates the driver- and passenger seats, cab frame, and cab ceiling. In the simulation process this allows for testing of the interaction between these components and to study the resulting ingress egress motion virtually.

The cab geometry and grab positions for hands create obstacles and foot positions internally. While imposing those inputs, the body automatically follows the direction of the foot avoiding the obstacles. These properties that the manikin will encounter while entering and exiting the cab are then passed to the digital human builder definition, such that task analysis can be performed.

DIGITAL HUMAN MODEL

To assess the interior and exterior of the vehicle, a manikin is placed in the digitized model of the *Mellowcabs* vehicle. *Human Builder* tools provided consist of: the generation of human body model, the definition of gender and height percentage, ergonomic analysis, action generation and advanced visual simulation.

Available human body databases of *CATIA V6* include African, American, Canadian, French, Japanese and Korean; the callable models include those of whole body, right forearm and left forearm; the provided reference points include eye reference point, the default reference point, left foot reference point, right foot reference point, minimum foot reference point and hip reference point.

The manikin is a 3D avatar of a 5th, a 50th, and a 95th percentile French/African population which is used as standard in setting up the driver and passenger position layout.

For the ingress and egress test, anthropometric measurements will be taken, for example weight and stature.

Figure 3.2: 3D Manikin of a 5th female, a 50th female, and a 95th male percentile French/African population (Author, 2015)

3.1.9. INGRESS & EGRESS SIMULATION

CATIA Ergonomics Task Definition provides functions to sequence activities and edit the sequence to assign tasks, which allows users to evaluate how a human will interact within a product or workplace environment.

High semantic activities such as reaching for an object, picking it up, or moving it are simplified through the use of *CATIA Ergonomics Task Definition*. Through the 3D immersive environment, the user can simply select the desired activity and apply it to the manikin and an object or location. The series of motions required to achieve that action are automatically generated. Additionally, the user can easily modify the proposed postures to fine-tune manikin activities to meet their specific needs. This is categorised as Foot Position Inputs and Hand Position Inputs.

POSTURE ANALYSIS

CATIA Human Activity Analysis is an add-on *to Human Builder* which enables to simulate how a human will interact in the context of a product or workplace environment allowing the user to maximize human comfort, safety, and performance.

For the context of this thesis a Rapid Upper Limb Assessment (RULA) is used for intuitive posture analysis. The user can visualize postural score and comfort assessment graphs. User-friendly dialogue panels provide postural information for all segments of the manikin according to the preferred motion zones. Colour coding techniques mean that problem areas can be quickly identified and updated to an optimized posture. Additionally the user can break up the overall range of human motion by defining specific human joint motion limits. These limits correspond to the preferred range of motion in terms of comfort, strength, and precision. The user can display the joint mobility limits and the comfort zones in graphical format. Finally, the user can manipulate the joint limit arrows, and can annotate postures.

3.1.10. DESIGN DEVELOPMENT

Participatory Action Research (PAR) has also been adopted as it values users as co-creators in the design process; not relying solely on the designer's own competencies (Sanders, 2007). This is needed, as it is crucial for potential future customers to be exposed to the product in the development phase when product characteristics are still being experimented with.

A co-design approach to design development will thus be undertaken (Steen, 2011). This is the method whereby a collection of experts including designers, outside experts, as well as pending consumers creatively collaborate (Steen, Manschot, De Koning, 2011: 53). The goal being to investigate and explore ideas utilising sketches, mock-ups and prototypes which can then be discussed and developed in an iterative fashion. Users are treated as experts in their own right (Steen, 2011). Throughout the design process, the above experts evaluate ideas according to their desirability. Once this has been done, the solutions are viewed through the lenses of Feasibility and Viability. These lenses are brought in during the later phases of the process (IDEO, 2012).

AESTHETICS

Potentially one of the aspects that the various disciplines of engineering give the least regard to is that of aesthetics. Although the popular saying "Form follows function" holds truth, in some instances; function alone doesn't always please marketing and sales. Generally, quality of components could be the big factor since one who has experienced at least one part of defect in their vehicle will actually affect their judgement towards other factors in the vehicle. Aesthetics can for a large part be linked to human emotion and the perceived beauty of the audience viewing it, but it can also be "honest" in what message it tries to relay to the audience. Invariably a link can be drawn to product semantics.. Technical constraints related to the manufacturing and performance of the *Mellowcabs* MMV, for example, the desired drag coefficient, material used and manufacturing processes take precedence above the styling of the vehicle, however, there is still no need to have something which is regarded as undesirable, therefore a compromise must be sought between the desired function and desired aesthetic.

SURFACE ANALYSIS

CATIA V6 Advanced ICEM Surface and Shape Design by *Dassault Systeme's (DS),* enables the product development team the creative freedom and precision to combine artistic style and engineering performance in the final design. This is to reach a result of fully functional designs, without compromising on the quality. When it comes to the quality of car manufacturing, consumer goods design and surface modelling, most major automotive companies and design studios put their faith in *CATIA V6 Advanced ICEM Surface* and *Shape Design.*

High quality surface modelling is essential for successful product design. To produce a reliable surface model at the first attempt, the modelling software has to be able to implement the most advanced mathematics for G0 to G3 quality surfaces, curves and forms. Not only that, to ensure the designer and the engineer get the results they really need, the software has to do this dynamically and interactively.

Therefore, the decided concept of the side-door design would be modelled on the *CATIA V6 Generative Shape Design* and *Freestyle Workbenches,* as referenced from the conceptual design process and the digitized model of the *Mellowcabs* vehicle. These workbenches specialise in the creation of wireframes and surfaces.

Once the surface of the side-door design has been modelled, a surface analysis will be performed with the design intent to analyse and understand the overall quality and discontinuities of the structure.

MOVEMENT SIMULATION

Similarly *CATIA V6* allows the design team to get feedback in terms of physical-based data that correspond to how the door, and its movement could hinder the passenger's interaction while they ingress and egress the vehicle. This enables the team to try various designs to perform a comparative study without building a single physical prototype.

With this in mind, the digitized model of the side-door design and the way in which it should move is simulated virtually in order to firstly determine whether the movement of the door is plausible, and secondly to determine whether clashes occur that could ultimately hinder the passengers interaction while they ingress and egress the vehicle.

3.1.11. SUMMARY

The purpose of this chapter was to describe the research methodology of this study, explain the sample selection, describe the procedure used in designing the instrument and collecting the data, and provide an explanation of the statistical procedures used to analyze the data.In the context of this thesis, factors to consider are passenger view (inside and outside), door entry and exit, rear passenger clearance and spaciousness, vibration and noise, and trunk space.

Thus, the previous section attempts to serve a solution the raised question whether virtual posture analysis can be utilized by Industrial Designers to evaluate the ergonomics of passenger's ingress and egress movements in MMV's.

It provides an appropriate research method, and research design to the design of ingress and egress systems for MMV's. Therefore the data collection and instrumentation for this thesis utilizes that of: Focus group meetings, Video analysis of ingress and egress motion, Virtual human factor simulation and Posture analysis, and Door design requirements.

Besides trying to establish the viability of a door design, the method also tries established the design's suitability in terms of usability, in any type of situation, such that it will not hamper the ingress or egress movements of humans or cause any other type of human discomfort.

3.2. THEORETICAL FRAMEWORK

In the following Theoretical Framework section, the major tenants of the theory; human centered design, product semantics, the human-machine system, ergonomic principles, and affordances, are highlighted as the most important and influential aspects towards dealing with the users and product at hand, and indicates how this theory relates to the proposed study.

The main aim is to use principles that advocate fun and user-friendly interaction between commuters and the side-door concept. This framework provides a direction of inquiry and a perspective from which to examine the main problem (TRENT, 2012). In the context of this paper, aspects of human centred design (HCD), product semantics, the human-machine system, and affordances allows for a body into which data from anthropometric, ergonomics, product and user trends can be integrated to inform the qualitative practices of this study.

3.2.1. HUMAN CENTERED DESIGN

Human centered design (HCD) is not a design style, but is a process for designing and developing products that is grounded in information about the people who will be using those (Brown, 2009). By utilizing the research findings on physical abilities, limitation, and task requirements, in order to provide operational solutions that enable all users to function at their highest capacity-regardless of age or ability.

As the design grows and develops the users should be included in every step and informed of the changes and asked for their responses on them. This method of design enables the designer to a real worldview of the final product before it is launched to market, which is an invaluable resource. Another positive of HCD is that rather than forcing the users to change their ways of doing things to fit the product, the product instead is designed to suit the needs of the user. Thereby establishing that for the design of a new side door, HCD is an important and influential aspect to have.

HCD also relies heavily on the empathy of the designer (Brown, 2009). It is critical that designers are able to understand the users and what they desire. If there is a difference between what the users wants and what the designer is designing, it will almost certainly result in a poor product.

Within this larger scope HCD techniques can be applied to create new solutions. HCD starts by examining the needs, dreams and behaviours of the target group. The first step is to listen and understand what users want. This is called the Desirability lens. Throughout the design process the world is viewed through this lens. Once this has been identified, the solutions are viewed through the lenses of Feasibility and Viability. These lenses are brought in during the later phases of the process (IDEO, 2012).

3.2.2. UNIVERSAL DESIGN

Considering the effective inclement weather can have on touch, visibility, behaviour and error performance it is deemed appropriate to consult design practices that deal with diminished capacity of the above. The basic premise of Universal design is to develop a design that can be accessed, understood and utilised by the largest range of people; regardless of size, age, ability or disability (Centre for Excellence in Universal Design, 2014).

As described by McAdams & Kostiovich (2011):

"The basic notion of universal design is developing a design that can be used equally well by people of any ability: in other words, it does not discriminate against users based on their ability. In this context, UD may be the most general term in use."

Universal Design utilises 7 general principles to guide and evaluate design intervention:

- equitable use
- flexibility in use
- simple and intuitive use
- perceptible information
- tolerance for error
- low physical effort
- size and space for approach and use (McAdams & Ostovich, 2011)

From a commercial standpoint, Universal Design also increases product appeal through broadening the potential target audience and making the user experience more pleasant. This is important considering adoption-rates of Micro-Mobility Vehicles (MMV's) led to the exploration of vehicle usability.

Universal Design Principles serves as a tool against which ideas can be benchmark, as well as a validation tool for evaluating eventual proposals.

To gain a better understanding of how Universal Design principles might manifest themselves physically, the theory of affordances assists in better understanding human/product interaction.

3.2.3. AFFORDANCES

Kannengiesser and Gero (2011:52) distinguish between three levels of affordances. Reflexive, Reactive, and Reflective Affordances.

REFLEXIVE AFFORDANCES

This is said to be a very direct form of perception; requiring little internal processing and correlates with a reflexive mode of reasoning. This form of reasoning relies on very little active decision making, instead it's a user's direct response to external stimuli. They include biological reflexes and learned responses through iterative use. These are intuitive affordances where there is a strict fit between the stimuli provide by the product and the user e.g. gloves and hands, stairs and feet, etc. These meta-relationships giving rise to affordances such as 'wear-ability' and 'clime ability' (Kannengiesser, Gero, 2011:54).

The use of various styles of door handle can be used as example; where users construct a schema for using this category of product. The user can then perform an action reflexively (Kannengiesser, Gero, 2011:55).

REACTIVE AFFORDANCES

This is an action possibility chosen from various possible action possibilities. The process is separate from the user's intention and affordance can be seen as arising from a searching process. Here multiple variations exist within a specific action possibility, requiring the user to choose one given a set of criteria. Each variation is tested according to a set of criteria until one is found that is satisfactory. An example given by Kannengiesser and Gero (2011:54) is the unlocking of an unknown door. An individual unsuccessfully attempts unlocking a door by turning the key in a certain direction, if that fails an attempt is made by turning it in the opposite direction at which point the user is successful. The user intention of unlocking the door by turning the key has not changed, but rather the value of the parameter (in this case the turning of the key) has changed parameters that could affect the same action. This can lead to a lower degree of confidence with the outcome of intended action.

REFLECTIVE AFFORDANCES

These relate to changes in expectations that arise from the situation within which a product is being used. Kannengiesser and Gero (2011:54) describe situations as "processes that influence what goals and concepts are constructed and how users interpret and interact with their environment." For example, a closed door can be interpreted a sign of privacy and thus affords 'knock-ability'. Alternatively blocking a door without a lock by jamming a chair under the door handle means that the door affords what might be called 'jam-ability'.

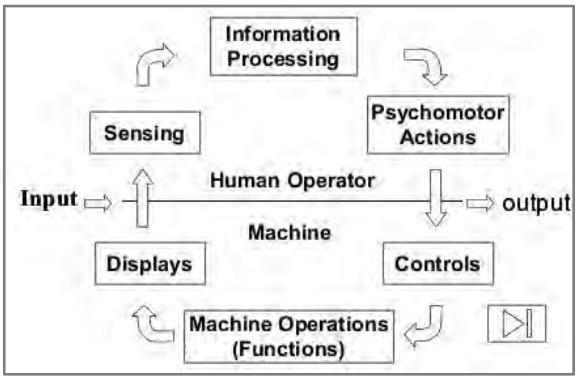
These are what is called hidden affordances; where seemingly no perceptual cues are provided by the artefact. This is an area where affordances should be viewed form an epistemological viewpoint, and thus Krippendorfs original theory of product semantics start playing a bigger role.

The framework for understanding and developing affordances thus need to go beyond a purely ontological basis.

3.2.4. PRODUCT SEMANTICS AND THE HUMAN-MACHINE SYSTEM

Norman states that product semantics emphasizes how products ought to function to what they mean to those affected (Norman, 2003).Thus product semantics concerns itself with the emotional aspect inherent between the product and the user. In the example of a vehicle, it should first and for mostly function as a means of transportation, but user orientated design or affective design, accentuates the experience of driving and the emotional connotations which humans attach to the product. Norman (2003) also states that "pleasant things work better". The psychological factors pertaining to affective design or cognitive ergonomics are something that cannot be overlooked and needs to be implemented in the design of the vehicle.

In the case of vehicle design it is imperative that the optimal driving environment is created with respects to safety, comfort, driver performance, product semantics and cognitive responses. The latter two mainly pertain to the Human-Machine system (HMS). According to the *Technische Universitaet* Berlin's Centre for Human-Machine systems, The HMS is a system in which the functions of a human operator and a machine are integrate to fulfil a task (TU-Berlin, 2013).



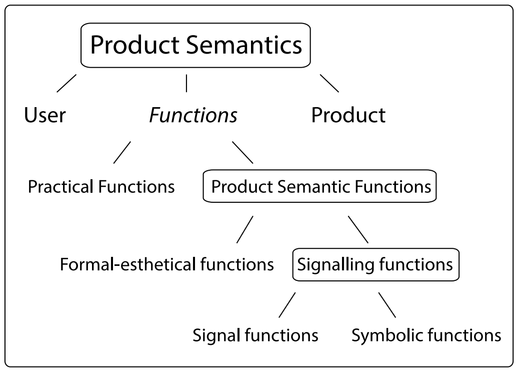


Figure 3.3: The Human-Machine System (Seojungko, 2009)

Figure 3.4: Product Semantics

Product Semantic is not concerned with the ontological nature of a product. Instead it has to do with how that nature is interpreted, filtered through human cognition and interaction. Krippendorff (1989:5) suggests that semantics aim to explore users' perception of how they attribute meaning; how it is acquired, grows and evolves when interfacing with physical products.

FIRST CLASS OF METHODS - DESCRIPTIVE

Ethnographic methods can be utilised to describe peoples 'use of objects as well as cultural habits and practices relevant in the context of MMV use.

Discourse analysis is one of the few ways in which you can get qualitative insight into peoples' world constructions. It also gives insight into the various as well as multitude of cognitive models users' employ when approaching a specific situation.

Krippendorf, (2011) also proposes the uses of perception experiment which can, "reveal how forms, configurations or movements are mapped into language or acted upon in concert with culturally established practices, thus going to the heart of the symbolic qualities of things"

SECOND CLASS OF METHODS - ANTICIPATORY

This attempts to extrapolate from people's perceptions, actions and usage in relation to current designs; the changes in perception, actions and usage that might arise when new designs are introduced. This is deemed important as peoples understanding of objects change with use and over time. Krippendorf recommends creating a dynamic theory of how the meaning of symbols change over time and through use, how motivation can sustain this growth to explore yet more untapped product affordances as well as how groups of users can appear around new and "emerging interface conventions." (Krippendorff, 1989:10)

Anticipating these actions requires extrapolation from existing knowledge. How users explore these complex affordances will be approached using Affordance theory as discussed later. These methods make sure that any proposed affordances embrace both the users' cognitive models at the time, as well as those that will emerge with use.

THIRD CLASS OF METHODS - CREATIVE

This class relates to how the semantic attributes and research data gets converted into the product and the actions they afford.

3.2.5. DESIGN THEORIES FOR PRODUCT SEMANTICS

Any design theory that adopts the above methods should be rooted in the following:

A general understanding happens when differing categories of experience (i.e. sight as appose to texture) are related to each other.

It is important to differentiate between, 'something making sense' and 'the meaning of something'. The former means to understand the role an object plays within a particular context, i.e. "a satisfactory explanation of what it does." The latter being the sum total of all the contexts that a user can picture utilising the product in (Krippendorff, 1989:12). Thus an artefacts meaning is always someone's cognitive constructions, regardless of whether it can actually live up to its perceived use. "The range of cognitive models or practices that a product can sustain is called its affordances." Within product semantics usage errors are largely attributed to a mismatch between meanings and affordance (Krippendorff, 1989:5).

With this in mind it is clear that the characteristics of a door are very important because those would be the parts of the vehicle that should indicate to the user where their hands should be placed and how the door should be operated. This should be accomplished through good design and the use and understanding of product semantic and affordance.

3.2.6. ERGONOMIC PRINCIPLES OF CATIA V6

Factors such as structure, size, shape, material and quality in each part of the side-door design may influence the handling, flexibility, stability and comfort in using, so all the design basis is decided by the human data of users. In order to solve the problem among human, machine and environment in the product designing process, *CATIA*V6 is the first to propose the solutions for man-machine design and analysis. Figure 5.3 shows the man-machine analysis processes of *CATIA V6. CATIA V6* has four "ergonomic design and analysis modules", including *Human Measurement Edit* module (HME), *Human Action Analysis* module (HAA), *Human Posture Analysis* module (HPA) and *Human Builder* module (HBR) which is used to measure the digitized data and to maximize human comfort, safety, and performance through a wide range of tools and methods that specifically analyse how a manikin interacts with objects in its virtual environment.

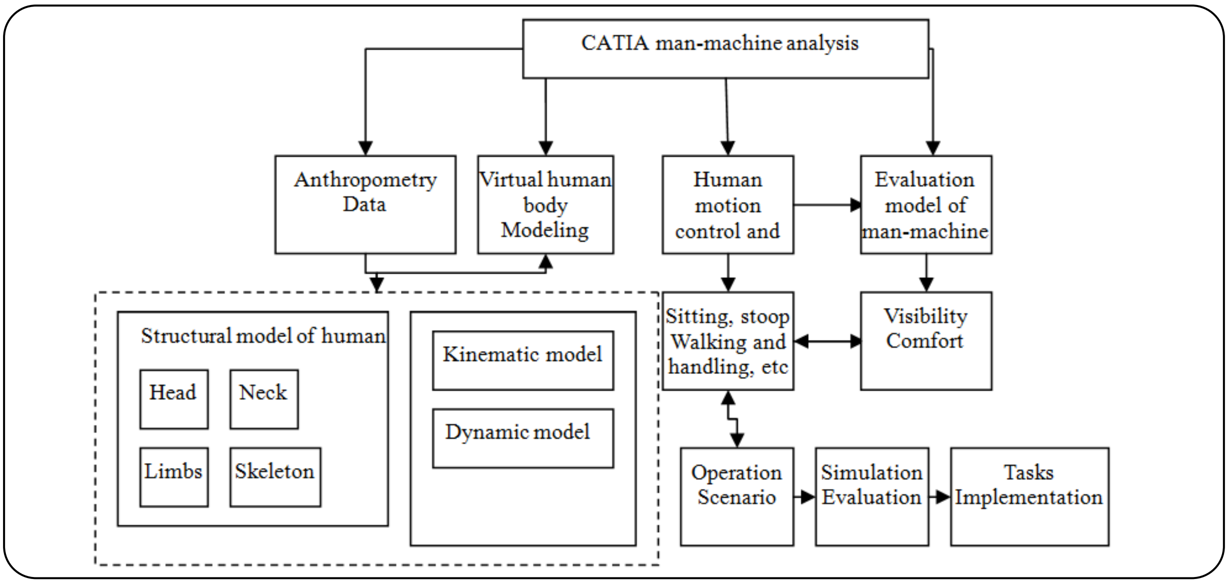


FIGURE 3.5: The man-machine analysis processes of *CATIA*

3.2.7. SUMMARY

This section discussed the details of the theory that is guiding the proposed project. From this theory, the designers were able to support the statement of the problem, the purpose of the study, the questions, the choice of instruments, and methodology of the study.

In this section, the major tenants of the theory; human centered design, product semantics, the human-machine system, ergonomic principles, and affordances, are highlighted as how the theory relates to the proposed study and this thesis. The eventual findings of the project will be discussed in terms of how they relate to the theory.

Therefore, for the purpose of this thesis in performing an ergonomic evaluation for a MMV design and proposing recommendations for improvement, a virtual model to perform ingress and egress motion had been developed. This enables testing of various designs to perform a comparative study without building a single physical prototype.

CHAPTER 4

4.0. FINDINGS AND RESULTS

The following chapter aims to understand who the commuters are that occupy the MMV method of transportation, and gain knowledge of their ingress and egress patterns. This usability study gives the design process a better scope of direction while still following the conceptual framework and qualitative research conducted.

This section presents the results gained from a virtual manikin to evaluate the ergonomic ingress and egress motion for passengers of a micro-mobility vehicle.

4.1. RESEARCH RESULTS

4.1.1. UNSTRUCTURED INTERVIEWS

- ***Neil du Preez*** – Entrepreneur, Mellowcabs CEO
- ***Chris Hendrikse*** – Industrial Designer, Avid Motorcycle rider, Cyclist

The use of names and information presented below was done with the full permission of participants.

Neil du Preez (du Preez, 2015)

Exploring the initial hypotheses, it first had to be determined to which extent vehicle usability might be hampered by changing weather conditions. Quantitative and qualitative information needed to explore the phenomena was gathered in discussion with *Mellowcabs* CEO Neil du Preez. Initial feedback in terms of vehicle performance and limitations were garnered. The effects of vehicle design in the context of Mr du Preez's desire to expand into global markets were also discussed, both in terms of regulations, classifications and laws.

The Mellowcab V2 is based on the Mellowcab V1 which was a re-imagined version of a European pedicab. These were very basic and due to it being predominantly pedal powered with only a small electric motor for support, limited by range, abilities, acceleration and outright speed. The V1 was never intended as a commuter vehicle that could seriously fill a gap within the greater multi modal transportation infrastructure of the future. While in terms of geometry, design and layout the V2 is very similar, it has been fitted with an all-electric power train allowing the vehicle to reach speeds of 45km/h (speed limited). While this makes the vehicle a much more viable option as part of the greater transportation system it does raise issue with the inherent limitations of the base design. Greater reliance on the vehicle could potentially require the vehicle to operate year round; the greater speed and effects of inclement weather possibly reducing vehicle appeal and adoption. To determine the extent to which this new environment will affect vehicle performance, as well as whether this will require additional adaptations (so users don't discard it as a viable transportation option), additional primary and secondary research was conducted. If indeed such changes are required it was also mentioned by Mr. du Preez that currently the National Regulator for Compulsory Specifications (NRCS) only has requirements relating to the frontal protection of MMV's, with none existing for the sides of the vehicle.

Christopher Hendrikse (Hendrikse, 2015)

The following feedback regarding real world adverse weather biking was garnered from an interview with Christopher Hendrikse.

Discussing the causes of wetting during riding, I was informed that on many occasions much of the wetting comes from spray by other vehicles. The extent depends very much on the position of the vehicle. If the vehicle is in front, the rider can expect to get wet from their visor down to their feet. If the road was merely wet and no rain were actually falling the spray would only reach the height of the rider's feet. Chris concurred that rain hitting the body as speed rises becomes increasingly noticeable, and that any exposed skin, or skin under thin clothing can feel as if it is being hit by speeding needles.

In terms of wind effects it was pointed out that while wind noise does not become painful until higher speed, discomfort already presents itself from speeds as low as 30km/h; well within the *Mellowcabs* 45km/h maximum allowed speed. As a cyclist he commented that even on a bicycle, sustained riding at 25kh/m can become 'annoying'.

Product Lifecycle Management Competency Centre

Candidates from within the *PLMCC* were identified to create a collective focus group, which had centrally focussed on the research problem at hand. The team consisted of Mechanical-Engineers, Electronic-Engineers, Project Managers, Technicians and Industrial Designers.

- ***Micheal Petersen - PLMCC Director / Mechanical Engineer***
- ***Adriaan Brodtrück - Industrial Designer***
- ***Prof. Mugendi M'Rithaa - Industrial Designer / Universal Designer***
- ***Jeff Ball - Mechanical Engineer***
- ***Naeem Cassim - Industrial Designer***
- ***Gerry Banda - Mechanical Engineer***
- ***Neil du Preez - Entrepeneur / Mellowcabs CEO***

See Table 4.1 below:

DATES	INDIVIDUALS	EVENT/DISCUSSED
AUG ‘14	Adriaan Brodtrück (Research Assistant) Neil du Preez (Mellowcabs)	Field Research at PLMCC: Investigating Micro-Mobility Vehicle and possible trends. Introduction to Mellowcabs
SEPT ‘14	Adriaan Brodtrück (Research Assistant) Michael Petersen (Mechanical Engineer)	Established Problem Area focusing on a Protective Side-Door System.
OCT ‘14	Adriaan Brodtrück Micheal Petersen Prof. Mugendi M’Rithaa	Discussion: Haptics and Tactile Feedback Human – Vehicle – Environment Virtual Human Factors
NOV ‘14	Jeff Ball Naeem Cassim	Group discussion at PLMCC: Cock-pit and Body parameters 2 doors; 1+1 configuration
DEC ‘14	Prof. Mugendi M’Rithaa	Product Semantics for Vehicles Discussion; Human – Vehicle – Environment Preceptor & Effecter System
JAN ‘15	Neil du Preez Naeem Cassim Gerry Banda	Door Design Requirements Human Factors-Design-Engineering
JAN ‘15	Virtual Simulation with 6 individuals Neil de Vos	Observation: Passenger Limb movement Tolerance Tests kinematic degree of freedom Driver Visual Clearance Cone of vision; Field of vision; Line of sight
FEB ‘15	Gerry Banda	Discussion at PLMCC: Mechanical Equivalence
FEB ‘15	Haptic Simulation and Usibility Study with 6 individuals	Observation: Challenges and techniques to ingress and egress Mellowcab
MARCH ‘15	Neil du Preez Neil de Vos	Lo-Fi Video Simulation Ingress Egress Simulation
MARCH ‘15	Naeem Cassim	Established Final Door Concept
APRIL ‘15	Naeem Cassim Neil de Vos	Discussion: Haptics and Tactile Feedback
APRIL ‘15	Haptic Simulation with 7 individuals	Observation: Challenges and techniques to ingress and egress Mellowcab
MAY ‘15	Naeem Cassim Gerry Banda Neil du Preez	Functions, aesthetics and user experience were discussed around virtual simulations.
MAY ‘15	Neil de Vos	Surface Analysis Door Movement Analysis
JUNE ‘15	Neil de Vos	Final Ingress Egress Virtual Simulation and Posture Analysis; Cone of vision; Field of vision; Line of sight
JULY ‘15	Naeem Cassim Gerry Banda Neil du Preez	Functions, aesthetics and user experience were discussed around virtual simulations of final concept on CATIA V6 Workbenches.

TABLE 4.1**:** Focus Group meetings and task discussions

4.1.2. USABILITY TEST & VIDEO ANALYSIS

Due to the unavailability of the *Mellowcabs* V2 vehicle, testing was conducted utilising the V1 version of the vehicle. As both vehicles are very similar in proportion, shape, layout and general design it was deemed sufficient to gain the desired feedback. Due to this vehicle being inoperable, no running wind and comfort testing could be done. Instead wind was simulated through spraying water from a position slightly in front, above and to the right of the vehicle centre line.

The main objectives were to simulate multiple conditions such as wet and dry weather running, night time usage as well as parking conditions. The usability test initially consisted of 5 activities, however due to one tester having to leave early; was reduced to four. Also due to impending rainfall, it was decided to do the dry test first instead of the wet weather simulation. Initially the wet weather simulation would have been conducted first to establish how participants would perform without any vehicle familiarity. The test eventually consisted of four short tests describe and summarised below.

Figure 4.1: Mellowcabs V1 (Image by Author, 2015)

DRY TEST

Conditions on the day: (conditions: highest average daytime temp. = 18°C; dew point temp. unavailable; precipitation = simulated/afternoon showers) (AccuWeather, 2015).

During the dry test participants were asked to approach the vehicle as they would a normal taxi in Cape Town. They were also encourage to verbalise the process, although not to the extent where it took too much attention from what they were doing. Participants were then asked to exit the vehicle.

Time for entry – From the right foot initial lift to seated position

Time to exit – From initial forward lean to both feat outside the vehicle

Participant	**A**	**B**	**C**	**D**	**E**
Entry Time(s)	9 (Jacket caught on protrusion)	4	5.5	5	4
Exit Time(s)	4	Approx. 2.5	3	3	2.5

Below is a general summary of the entry process including: any fouling, hesitation or confusion observed.

- All participants utilised the left door sill to aid entry with their right hand.
- Most used their left hand to lever themselves inside via the driver's headrest;
- potentially fouling the area where the drivers head would be.
- One participant reached for the roof rail with his left hand to aid entry and found no
- point for leverage in that area.
- Another utilised the centre of the passenger seat together with the side sill for leverage.
- Video analysis also shows participants fouling/interfering with an area that would be
- occupied by the drivers arm; leading to either the driver or passenger having to alter
- behaviour.
- This could also possibly be the cause for one of the participant's jackets catching and
- ripping on a protrusion on driver's seat.
- No confusion was shown in terms of foot placement.
- Lack of indentation below seats seemed to put participants off balance while pivoting
- into sitting position.
- Vehicle side sill height, shape and angle afforded its use as an armrest by most
- participants.

Below is a general summary of exiting the vehicle including: any fouling, hesitation or confusion observed.

- Participants used either the passenger seat or drivers headrest (again causing possible fouling), and the left sill to aid exit.
- Possible lack of heel space indentation might magnify the above issue.
- One participant had a small hesitation on exit due to the high sill.

Participant Comments:

- One participant commented that although the seat was comfortable, the material felt as if it is something from the ‘army’.
- This participant also felt the roof to be claustrophobic and suggested the front screen reach further back – An issue addressed in version two of the vehicle.
- The visibility of mechanical parts was also off putting to some, although this issue as well has been addressed in the newer vehicle version.
- Participants expected ingress and egress to be difficult because of the high appearance of the floor sill, however were pleasantly surprised by the ease with which they accomplished the tasks.
- A storage space would also be a helpful addition, although not one that is hidden; as some participants commented that they tend to forget things that are locked away.

Figure 4.2: Initial reach for leverage fails (Image by Author, 2015)

Figure 4.3: Participants utilising sill as armrest (Image by Author, 2015)

WET TEST

Here participants were simply required to approach the vehicle as directed and enter the vehicle. The participants were required to sit in the vehicle for a minimum 1-4 minutes before exiting the vehicle. Initially all four participants were required to complete four minutes, however the extent of water ingress was greater than anticipated. It was also appropriate as commuter journey time will vary. (Note that at this point participants have already established a familiarity with the product during the dry test. Also, participants were not required to perform any verbal tasks as in the dry test).

Time for entry – From the right foot initial lift to seated position

Time to exit – From initial forward lean to both feat outside the vehicle

Participant	**A**	**B**	**C**	**D**	**E**
Entry Time(s)	4	4	3	5.5	4.5
Exit Time(s)	7	4.5	3	5	4.5

Much of process was similar or the same to that of the dry test. Below is a general summary of notable changes that occurred during the wet.

- Participants no longer used the side sill as an armrest.
- Most visibly tried to isolate themselves and readjust their positions closer to the centre
- of the seat.
  (The above would influence the usage of the separate left and right safety belts; affecting safety)
- Participants immediately adopted a noticeably less comfortable and relaxed posture as well as facial expressions.
- Those wearing jackets with hoods did not remove them; even while inside the vehicle

To simulate the effects wind or wind gusts might have, water was sprayed at a slight angle from above. The vehicle was also mildly shaken to simulate driving over bumps; resulting in the following:

- Participants reacted with surprise as to the amount of extra water entering the vehicle.
- Participant A used an additional jacket to cover her legs.
- Water droplets bounced off the side sills and into the cabin.
- At this point, even situated in the centre, participant's arms were getting wet from direct and indirect effects.
- During mild shaking water streamed into the cabin from the roof. The roof rails acting like slingshots projecting water into the cabin.
- Approximately one minute into the test of participant A, water had started to pool inside the vehicle.
- The seat had also become saturated either side of the passenger, prompting her to lift herself out of the seat to avoid getting her pants wet.
- During the test of participant B the backrest had also become visibly wet. By the time participant D was tested the backrest either side of the passenger was completely saturated, with no visible dry spots.
- The seat at this point had become soaked through.
- Participant C also commented that his feet were getting soaked.

Summary of wet weather Questionnaires

General perception related to ingress and egress:

- Entry was deemed fairly easy and simple by all – however participant B voiced concerns about the rounded entry step and its potential for causing slippage
- Only participant C &D felt slipping to be a general risk; bemoaning the puddle of water on the floor. However the three other participants did recommended the adoption of some sort of non-slip grid or flooring.
- Two of the participants bemoaned the lack of a grab handle to hold on too when entering the vehicle.
- Participant A and E also felt they had to be cautious not to bump their head against the roof rail upon exit.
- Most felt wet egress was easier than entry, however compared to dry weather egress it was significantly slower. (This might more be due to relief of getting out of a very wet vehicle)

In relation to usage:

- The majority of participants initially felt that water ingress was not too bad, however they revised their position when wind and road bump simulations were done. Most felt the vehicle interior became wetter than expected during these tests; with participant D noting that he was unimpressed by the soaking wet seat and water constantly seeping in. Participant E also bemoaned the amount of water running down his buttocks.
- Most felt the seat was comfortable, however the material was deemed too raw and rigid.
- Participants also felt isolated as few dry areas remained inside the vehicle; phrasing it as a feeling of restriction and discomfort.
- Virtually all participants felt that it would be a great vehicle for summer use.
- However, participant B showed a particular aversion to the idea of utilising this vehicle for longer journeys in winter conditions.
- This sentiment was echoed by the others, with none feeling that the vehicle provides enough weather protection for CT winters.
- Neither do they feel the vehicle provides enough protection from wind.
- Participant B proposed the adoption of a door for winter times, while participant C recommended the adoption of at least some sort of protection.

Figure 4.4: Test Setup (Image by Author, 2015)

Figure 4.5: Surprise at the amount of water ingress during wind simulation (Image by Author, 2015)


Figure 4.6: Seat soaked through (Image by Author, 2015)


Figure 4.7: Water pooled inside Vehicle (Image by Author, 2015)

LOW LIGHT TEST

Reduced lighting tests to simulate evening and or heavily overcast conditions required participants to wear visibility impairment devices and perform an ingress and egress test. This consisted of a mix of pin-hole goggles that reduce the brightness of peripheral vision (simulating wearing a hood), and sunglasses to cut down on the overall brightness (National Heath Treasury, 2015). No waiting was required for this activity. The user was just required to sit comfortably before they exited the vehicle. A few short questions were asked in a post-test questionnaire.

Figure 4.8: Pin-Hole Glasses (National Heath Treasury, 2015)

Time for entry – From the right foot initial lift to seated position

Time to exit – From initial forward lean to both feat outside the vehicle

Participant	**A**	**B**	**C**	**D**	**E**
Entry Time(s)	Approx. 14	5	5.5	7	5.5
Exit Time(s)	4.5	5.5	4	3.5	4.5

Much of process was similar or the same to that of the dry test. Below is a general summary of notable changes that occurred during Ingress in low light conditions:

- Participant A's initial reach for the left side sill failed upon first try.
- She also exhibited tentative positioning of the entry (left) foot.
- Additionally she first utilised the left side sill and then the right side sill for support before pivoting into place.
- Participant D experienced slight foot interference by left hand sill.
- All participants immediately tried to adopt central seating position, with participant D tentatively adjusting his seating position to attain a comfortable spot to the left.
- During this manoeuvre he found his head bumping against the crossbar. The same was experienced by participant E.
- Additionally participant E also expressed doubt over head clearance upon exit.
- Participant E also tentatively looked at foot positioning although with no error as such.

Much of process was similar or the same to that of the dry test. Below is a general summary of notable changes that occurred during Egress in low light conditions:

- Participant B shows visible confusion about foot placement upon egress.

Summary of Participant Questionnaires:

- All participants would appreciate the addition of an interior light.
- Participant B preferred to approach the vehicle more cautiously in low light condition, and was not sure about the placement of hand supports.
- Participant D felt the low light conditions made him misjudge the step in height;
- As well as made it difficult to judge the space inside the vehicle.
- Participant E commented that he lost the sense of 'openness' he felt in previous testing.

Figure 4.9: Participant reaches for but misses Side Sill (Image by Author, 2015)

TIGHT SPACE ENTRY TEST

The tight entry test was not timed, however a 500mm gap between the vehicle and the wall was set to test whether the ingress and egress could be performed comfortably in real life condition. None of the users experienced ingress problems without any luggage, although the addition of a bag might cause parts of it to scrape against the vehicle or any object adjacent to it.

Figure 4.10: 500 mm Gap to Wall (Image by Author, 2015)


Figure 4.11: Entry and exit without Bag unimpeded (Image by Author, 2015)


Figure 4.12: Slight Impedance with Bag (Image by Author, 2015)

4.1.3. MOVEMENT ANALYSIS

Ingress

The ingress movement begins with the passenger walking to the open cab door geometry such that he is faced parallel to the side-door geometry. Once the passenger reaches the cab, he then grabs the outer door frame with his right hand while simultaneously stepping in with his right leg. The second step of ingress involves the left foot stepping of the ground emerging the body to manoeuvre through the door geometry such that both feet are placed inside the cab. During the stepping-in phase, the door frame on either side of the passenger and the ceiling frame above the passenger are considered obstacles to avoid. In the final step of the ingress, the right hand is placed on the driver seat head rest, while the body rotates in front of the passenger seat placing the feet perpendicular to the seat before the passenger sits down.

Egress

Egress movement starts from the sitting position. The first step is the passenger placing his left hand on the outer door frame while similarly placing his right hand on the driver seat head rest, sliding forward along the seat toward the front. During the second step of egress, the right hand is moving from the driver seat head rest while the body rotates towards the door geometry. The final step of egress is the left foot exiting the cab, then the right foot stepping off the cab floor while the left hand is supporting the body on the outer door frame. During the final step, the passenger steps out such that he faces away from the cab and walks away.

HAND POSITION INPUTS

To adhere to the three points of contact safety regulations in Section 2.2.6., the passenger must grab something for their safety while moving into the cab.

During ingress the manikin grabs the outer door frame with the right hand to support the body weight while stepping in with the right leg into the cab. In the final step of the ingress, the right hand is placed on the driver seat head rest, to support the body rotating in front of the passenger seat.

During egress the passenger places their left hand on the outer door frame while similarly placing their right hand on the driver seat head rest, to support the body sliding forward along the seat. During the second step of egress, the right hand is moved from the driver seat head rest to allow the body to rotate towards the door geometry. The final step of egress, the left hand supports the body weight on the outer door frame.

Hand position itself were predicted and analyzed during the movement analysis in section 3.1.5.; then given directly to the manikin in the stipulated cab geometry.

FOOT POSITION INPUTS

Foot position are defined by the size of the passenger foot, passenger seat, the location of the door, the height of the cab floor and the width of the space the manikin can move in. Foot positions are determined by ingress and egress.

The first foot position input is such that both the manikins' feet are facing with toes to the side-door entry geometry. The second foot input is when the manikin is stepping in with the right leg, with the left foot still on the ground. The third foot input of ingress involves the left foot stepping of the ground emerging the body to manoeuvre through the door geometry such that both feet are placed inside the cab. During the fourth input of the ingress, the feet are placed perpendicular to the seat before the passenger sits down.

The fifth foot input starts from the sitting position with the feet parallel to each other and placed perpendicular to the seat. The sixth foot input during the egress is the left foot exiting the cab, with the right foot still on the cab floor. The seventh foot input involves the right foot stepping off the cab floor with the left foot flat to the ground. During the eight foot input, both feet are on the ground facing toes away from the cab.

Foot position itself were predicted and analysed during the movement analysis in section 3.1.5.; then given directly to the manikin in the stipulated cab geometry.

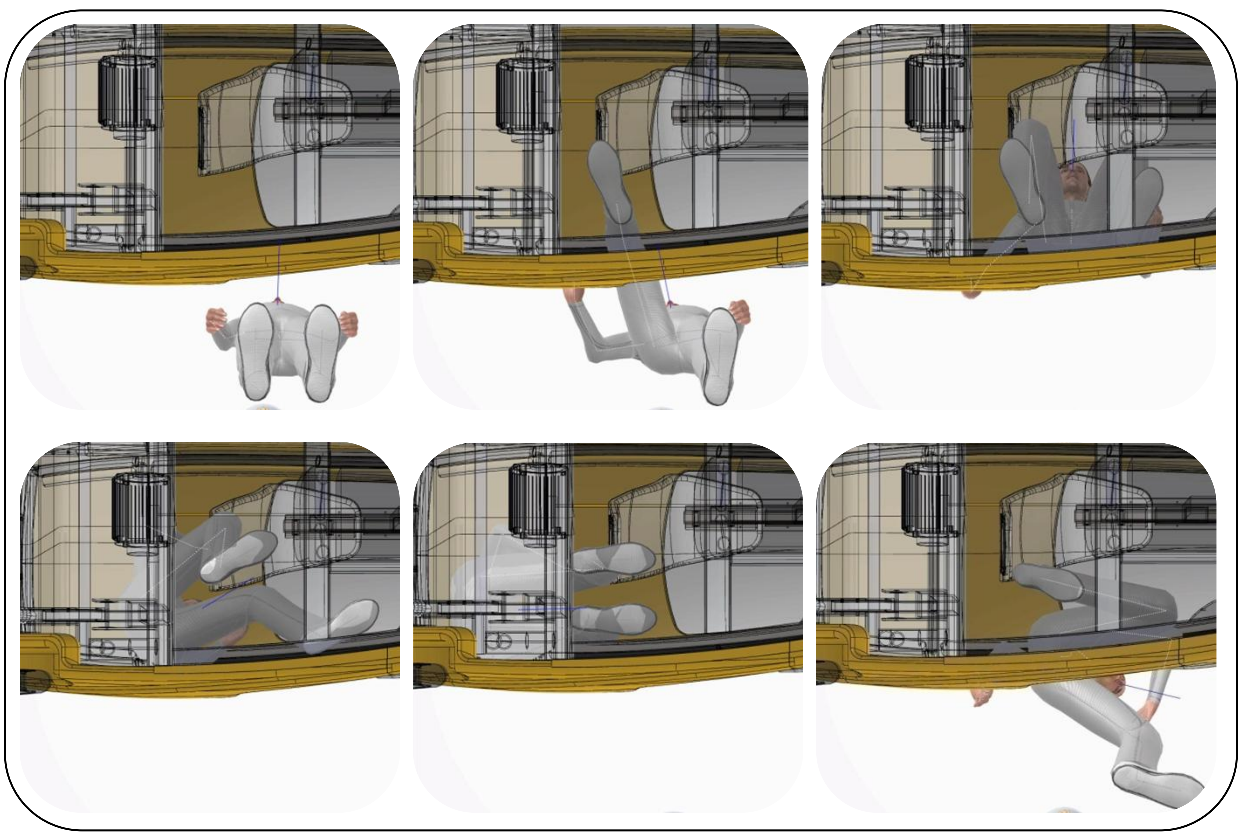


Figure 4.13: Foot Position Inputs (Author, 2015)

DISCUSSION

The majority of the participants found it fairly easy to enter and exit the *First Edition Mellowcab Pedicab* vehicle; however participants were continuously aware of the step height and made use of the driver seat as support. It was found that the *First Edition Mellowcab Pedicab* vehicle is not water tight and has no water drainage system, which explains the build-up of water dams within the cab. Participants were not impressed with the performance of the vehicle in wet conditions.

Additionally participants added that non-slip gridding or flooring should be considered, especially on the rounded edges as it causes slipping. Finally the participants commented that the *First Edition Mellowcab Pedicab* vehicle does not provide enough weather protection for the Cape Town winters, and that a side-door could benefit in this regard.

In the low visibility conditions, the participants found the ingress and egress tasks more difficult to perform. The participants were more cautious as they were unsure about head space, hand placement, and the judging of the overall space inside the cab. Each participant found the “kerbing “sufficiently visible when trying to exit the vehicle. Additionally, participants comment that lighting inside the cab would aid in creating a sense of space within the vehicle.

4.1.4. MATHEMATICAL MODELLING

The following Wind-Tunnel data were checked to corroborate secondary research relating to moving vehicles. The high air pressure against the rear bulkhead combined with reduced air velocity and turbulent streamlines points to air backflow and rotation in the region of the rear passenger area. This is due to a low pressure region caused by the large pressure differential between the front and back of the forward fairing.

Simulation type	steady
Element count	10548492
Run time (Elapse time)	0.892 h
Wind_Tunnel_Inlet	10.00 0.00 0.00 m/s
Drag coefficient, Cd	0.825
Lift coefficient, Cl	-0.395

Table 4.2: Fluid dynamic modelling - parameters (Kitzler, 2015)

For reference 10 m/s = 36km/h

Wind tunnel, bounding box	[0.000, 10.000], [-2.000, 2.000], [0.000, 3.000]
Body, bounding box	[0.705, 3.745], [-0.583, 0.585], [0.000, 1.827]
Wind tunnel dimension	10.000 m x 4.000 m x 3.000 m.
Body dimension	3.039 m x 1.169 m x 1.827 m.
Frontal ref. area, Aref	1.729 m^2
Blockage ratio %	14.4083333333
Distance inflow - body	0.705 m

Table 2: Geometric Dimensions

Table 4.3: Fluid dynamic modelling - parameters (Kitzler, 2015)

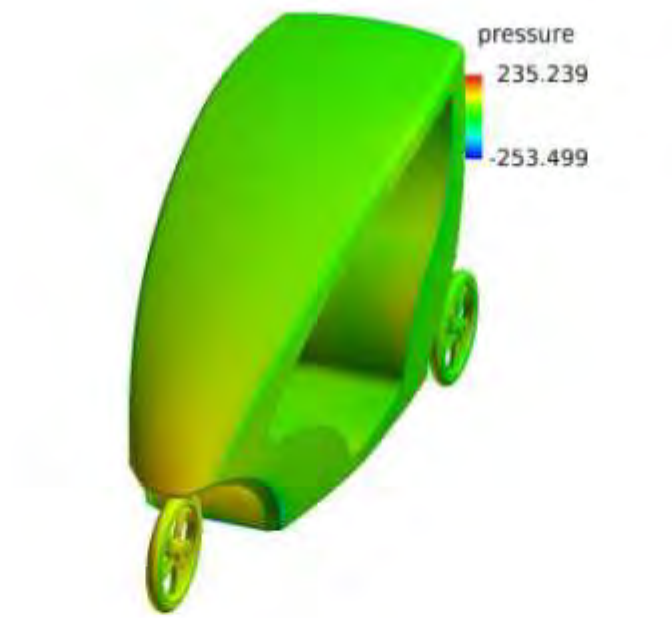


Figure 4.14: Body Surface Pressure Contours (Kitzler, 2015)

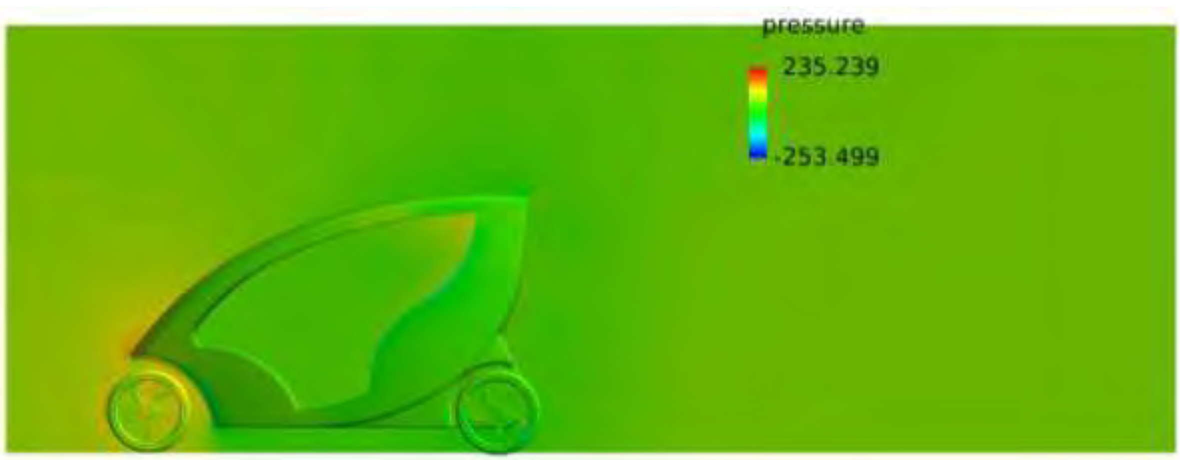


Figure 4.15: Mid Plane Pressure Contours (Kitzler, 2015)

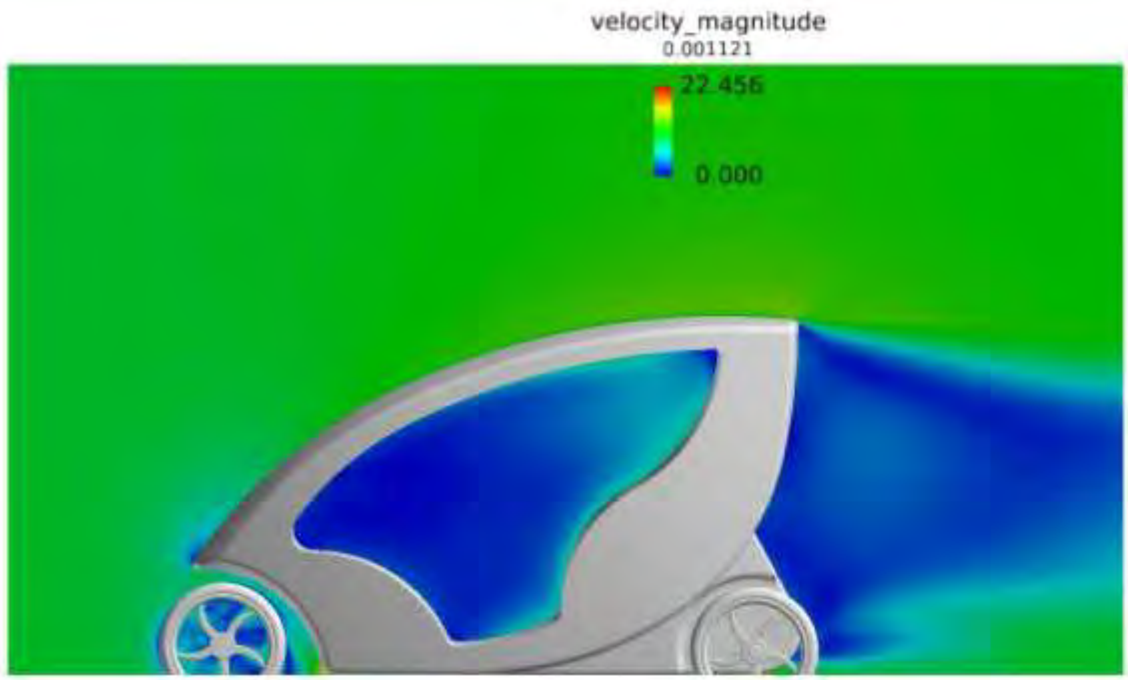


Figure 4.16: Mid Plane Velocity Contours (Kitzler, 2015)

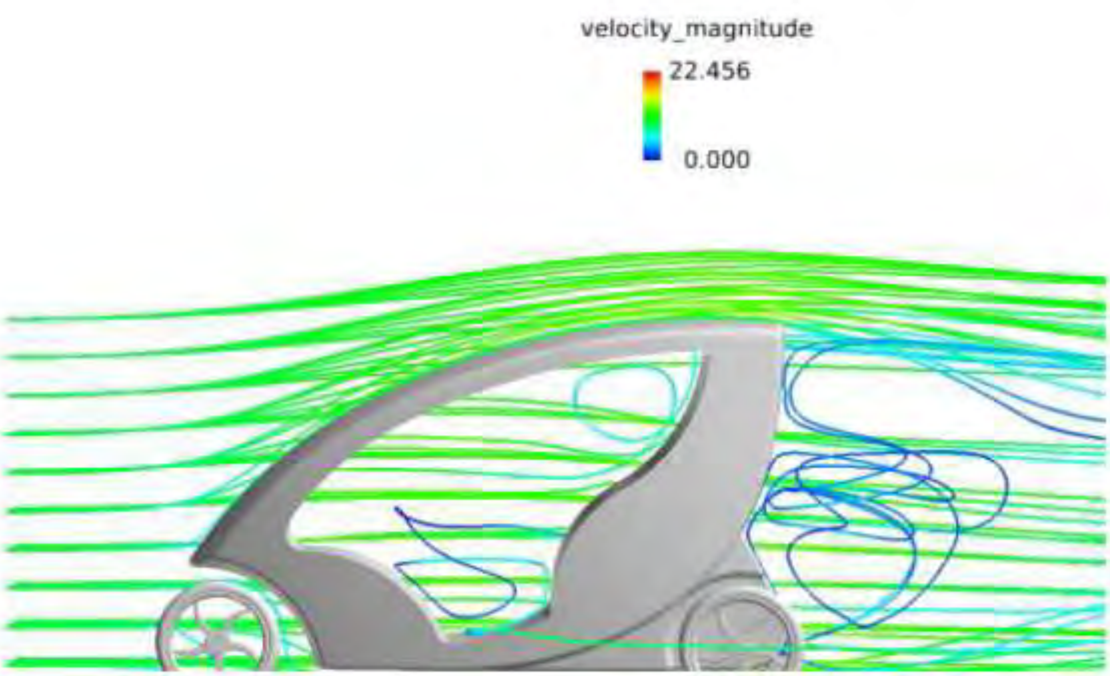


Figure 4.17: Streamlines Side View (Kitzler, 2015)

4.2. DESIGN REQUIREMENTS

Mellowcabs immediate next design requirement is the development of a good protective side-door system. This would isolate passengers in adverse weather conditions, and create a perception of the new concept door being at the same time elegant, smart, fashionable, comfortable, economical, manoeuvrable and safe. *Mellowcabs* wants to build up a new image for their new vehicle, which should have the perception of being safe, reliable and a constant method of transportation.

Additionally the client has inquired that the final product should be designed with the aim to be produced and implemented commercially. Therefore the requirements for the design of the new side-door system have been divided into the following three sections by making use of a multi-disciplinary approach.

4.2.1. HUMAN FACTORS AND OCCUPANCY

The requirements regarding human factors and occupancy were to focus on the passenger's experience of the vehicular comfort and safety during ingress and egress. The ergonomist would study the environment inside and outside of the vehicle geometry, concentrating on the human factors of ergonomics, anthropometrics, comfort, manoeuvrability and accessibility. This describes the requirement of a virtual human model or manikin to perform ingress and egress motion for a MMVs. The objectives were to provide information on the most relevant ingress and egress patterns with respect to car geometry and to evaluate human comfort associated with MMV ingress and egress, to thus quantify the effects of the fundamental design parameters of the side-door.

4.2.2. DESIGN

The requirements regarding design were to focus on the design of the door aesthetics and the ergonomics related to it. The designer in charge would study the characteristics of door designs within automobiles, since according to the NRCS; there are no compulsory requirements or specifications for the design of a side-door. Windows were a necessity; thus the designer had to try finding a balance between aesthetics and advertising space on the external surface. Regarding inside door detail, the designer similarly had to find a balance between aesthetics and functionality with the first priority being aesthetics. Ideally the doors should be detachable such that they can be removed seasonally. Ergonomics and functionality of door handles and hinges are also focussed on.

4.2.3. ENGINEERING

The requirements regarding engineering are to focus on the design of the door functionality and safety. The objectives of the engineer is to develop a mechanical mechanism to perform the opening and closing of the door, and to evaluate the stress analysis and kinematics of the door mechanism to thus quantify the fundamental safety and functionality design parameters of the side-door.

4.3. DESIGN DEVELOPMENT

The objective of this chapter is to utilise both a theoretical basis and data collected to design vehicle additions and adaptations that promote improved usability during adverse weather conditions.

Universal design principles were considered throughout the design process; utilising anthropometric data and co-design methods such as focus groups, co-design sessions and user validated prototypes to determine appropriate solutions. Taking this approach directly affects the design of mechanical components and layout, as such this paper will also include a short overview of the thought process that guided their design.

4.3.1. FIRST PHASE: INITIAL DESIGN CONCEPTS

As has been verified in the previous sections, keeping passengers dry and isolated from wind and rain are the main priorities in improving the vehicles adverse weather usability. Early concept proposals based on testing feedback and Secondary Research were scrutinised in a co-design session with Mellowcabs CEO Neil Du Preez, Engineer Gerry Banda and Designer Neil de Vos.

Figure 4.18: Co –Design group (Author, 2015)

The merits of less orthodox designs such as inflatable bladders resembling a 4-demensional lifejacket (inspired by inflatable leg covers), as well as more conventional deflectors, door and window designs were discussed (Figure 4.25).

In terms of their usability the former as well as other temporary material solutions caused potential issues such as increased step-in/out height, reduced entry aperture size, poor visibility and potential poor ease of use; with few participants liking the idea of cumbersome zippers or Velcro keeping the doors shut. Some proposals were also deemed either too complicated or were disliked for their semantic message; the sliding doors giving the impression of a van and thus not appearing particularly trendy. These were therefore not taken forward as they violate the majority of universal design principles in terms of reducing error (Chapter 3, Universal Design and Affordances).

The design process had focused on creating a concept for a new side-door; however, it had to be kept in mind that the product should be elegant, smart, fashionable, comfortable, economical, manoeuvrable and safe.

Therefore, the concept development of the new side-door design is in reference to the *Door Design Requirements* as stated by *Mellowcabs* and the *PLMCC* in section 4.2.. These requirements together with the *Investigation and Literature review* aided in educating the conceptual design process to deliver three different design concepts. Each concept simulates the door being closed shut, and open to the maximum angle of degree.

CONCEPT MC-A:

Concept MC-A features a *5mm Clear Plexiglas Resist 65* material (Appendix Q), Classic Rotating Door structure, which is divided in three sections; a front fixed side window, a movable door, and an adjustable side rear window. The structure features a similar shape to the entry of the vehicle geometry, hence with a slight enhanced offset to compensate for insulation. Being a common design, the assembly becomes easy to fit, cheap and also simple. Yet, it has a disadvantage in parking situations because of the huge lateral space that is needed for its operation.

Figure 4.19: Door Concept MC-A (Cassim, 2015)

CONCEPT MC-B:

Concept MC-B features a *5mm Clear Plexiglas Resist 65* material (Appendix Q), vertical opening Scissor Door structure, which is divided in two sections; a large movable door, and an adjustable side rear window. The structure features a similar shape to the entry of the vehicle geometry, hence with a slight enhanced offset to compensate for insulation. The door movement and aesthetics are pleasing, although height should be considered thoroughly.

Figure 4.20: Door Concept MC-B (Cassim, 2015)

CONCEPT MC-C:

Concept MC-C features a *5mm Clear Plexiglas Resist 65* material (Appendix Q), Gull wing Door structure, which is divided into three sections but simulating only that of two features; a large movable folding door, and a front side window. The structure features a large surfaced shape to the entry of the vehicle geometry, hence with larger enhanced offset to compensate for insulation. Other than height, the same disadvantage to parking situations can be found in a gull wing door, although this door makes for an easier entrance as its opening is in the upper side of the vehicle. Additionally, this concept is the heaviest of the three, due to the larger surface area and special mechanisms involved to operate the door.

Figure 4.21: Door Concept MC-C (Cassim,

DISCUSSION

A comparison among the three design concepts was carried out. The discussion explains the main differences between them, which is in the opened position. The models are shown below:

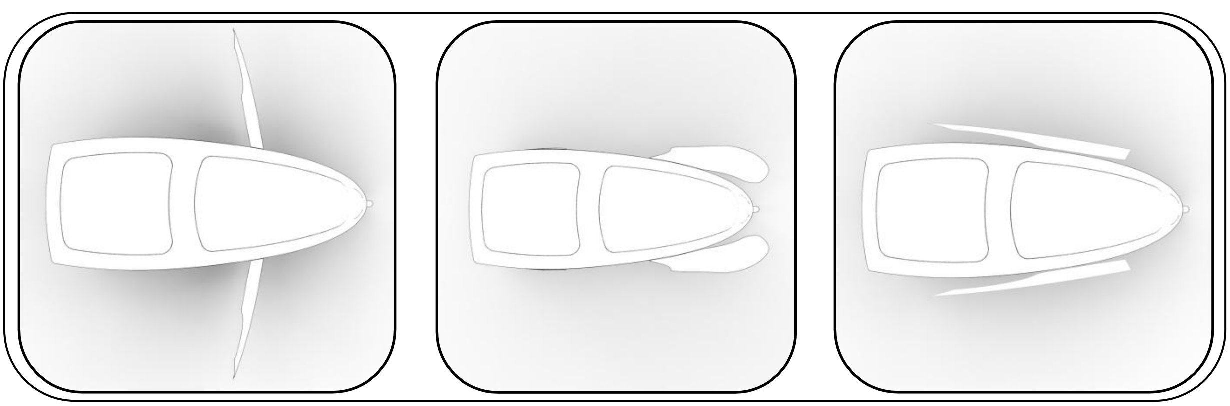


Figure 4.22: Door Opening Discussion (Author, 2015)

Concept MC-A presented a “classic door” which needs more space when opening which is a disadvantage. Concept MC-C presented a “gull wing door” that has to fold first to save lateral space which makes it heavier, and needs more height space - another disadvantage. Besides the way of opening it, these two concepts can cause the door to hit the door of other cars, or roof ceilings. In Concept MC-B, the door pivots vertically to the front of the vehicle which saves space when opened. Concept MC-A needs around 1.1 m and Concept MC-B needs 0.15 m of lateral space.

Figure 4.23: Initial Design Concepts (Cassim, 2015)

The two ideas relating to vehicle weather protection that were considered viable, and thus taken forward, were common Horizontal Rotating style doors as well as Vertical Scissor doors (Figures 4.24 & 4.25).

Figure 4.24: Horizontally rotating doors (Cassim, 2015)

Figure 4.25: Vertical Scissor doors (Cassim, 2015)

To help foster an increased sense of assuredness various hand rail designs were considered; all complying with the Americans with Disabilities act (ADA) requirement that any rail or entry/exit support should be accessible from outside the vehicle (Figure 4.26) (Chapter 3, Universal Design and Affordances). Seat backrest and floor mounted rails were ruled out as they take up space in an area that was shown to be limited in earlier user testing (Chapter 3, Usability Test and Video Analysis). A solid roof rail had the disadvantage of causing a hard obstacle in the region of the commuter's head; leading to potential injury and requiring the user to bend their necks upon entry. Solid rails would also need to be manufactured from steel; adding more weight and requiring dip moulding or some sort of foam cover to ensure good tactile usability. While intuitive, these designs lacked sufficient space, lacked sufficient safety and required too much effort to comply with Universal Design (UD) principles.

A soft hand rail attached to the roll-cage was deemed suitable as it can be made low enough to reach easily without causing a solid obstacle; meeting additional UD criteria for being flexible in use and tolerant of error. Given the design of the vehicle with its high-strength rolecage; no additional attachment point would need to be fabricated; reducing complexity and cost. This together with the side sill provides what is called a '3-point stance' while entering or exiting; deemed a necessity to ensure commuter safety by (Chateauroux, 2009).

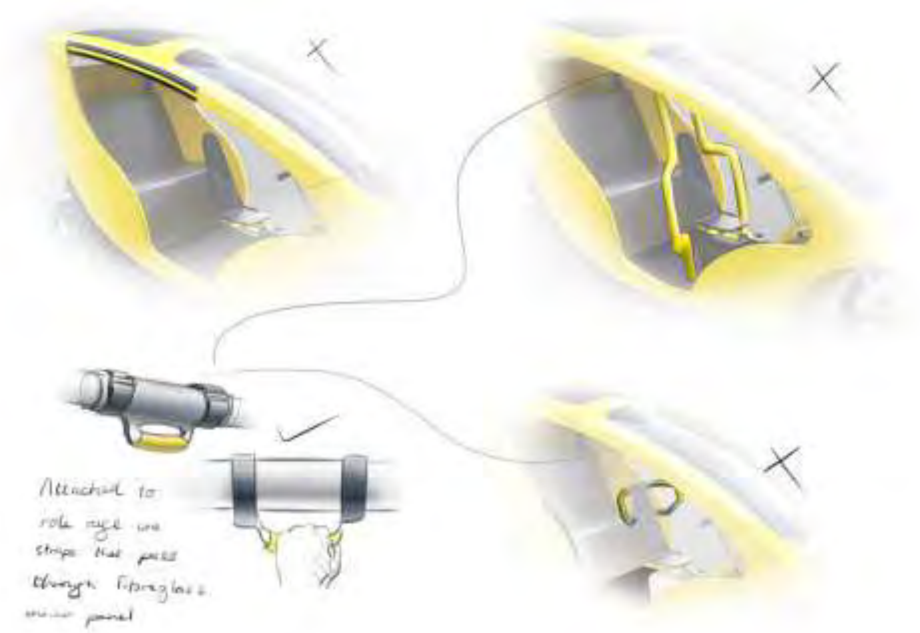


Figure 4.26: Grab Rail Design Concepts (Cassim, 2015)

As proven through usability testing, adverse conditions hamper visibility. It was thus attempted to adhere to ADA requirements regarding exterior lighting. Low mounted LED lights that prevent direct glare into a commuter's eyes were proposed (Figure 4.27). The theme of 5 separate LED's is carried over into the interior where 5 non-slip illuminated strips provide high luminance contrast to afford accurate foot positioning. Like the grab rail, various off the shelf solutions exist that have already been proven and validated (4wheelparts, 2015). Thus for the lighting, non-slip interior flooring and the roof grab rail, this paper will focus solely on aspects related to universal design. Lowering the vehicle step in height was considered however again this would require extensive modification to vehicle body moulds.

Based on what was found in terms of radiative heat and the large exposure area inside the vehicle a detachable inner sleeve manufactured from a material with low radiative heat properties was also proposed. This was done to reduce body heat loss to the large uncladded vehicle surfaces in close proximity to commuters. Exploring this idea further, it was decided to incorporate the window with the sleeve to ease removal (Figure 4.27).

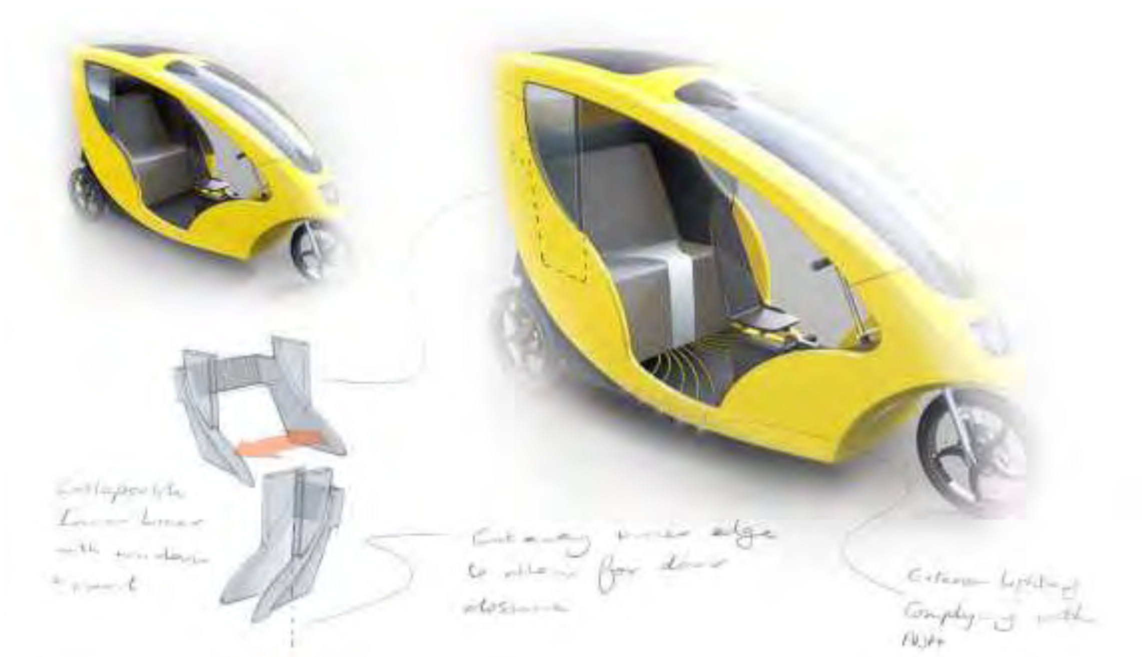


Figure 4.27: Usability Adaptations (Cassim, 2015)

4.3.2. SECOND PHASE: DOOR CONCEPT VALIDATION AND SELECTION

Dassault Systems CATIA lifecycle management tool was utilised to validate ingress and egress clearance between users and the two door concepts. A parametric based virtual CAD model developed was utilised to measure any impedance that may occur. A manikin representing a 95th percentile French/African male, a 50th percentile French/African female, and a 5th percentile French/African female(the standard when determining driver and passenger layout) was utilised. This was done as constructing full scale prototypes for validation would be prohibitively expensive. CATIA was also utilised to model the dynamic motion of any door and door mechanism to identify any other issues.

Figure 4.28: Manikin representing a 95th percentile French/African male (Author, 2015)

As can be seen in Figure 4.29 (Horizontally Rotating Door) and Figure 4.30 (Vertical Scissor Door), the initial concepts caused considerable hindrance upon entry; the proposed window fouling the area participants used for leverage during earlier usability testing. These aspects are likely to cause entry errors and significantly increase the effort exerted by commuters when entering and exiting the vehicle. Adjustments were made to the positioning of the 3-quarter window; pushing it back on both concepts to allow for adequate arm and hand clearance upon entry and exit. Increasing this space should significantly simplify the processes of ingress/egress.

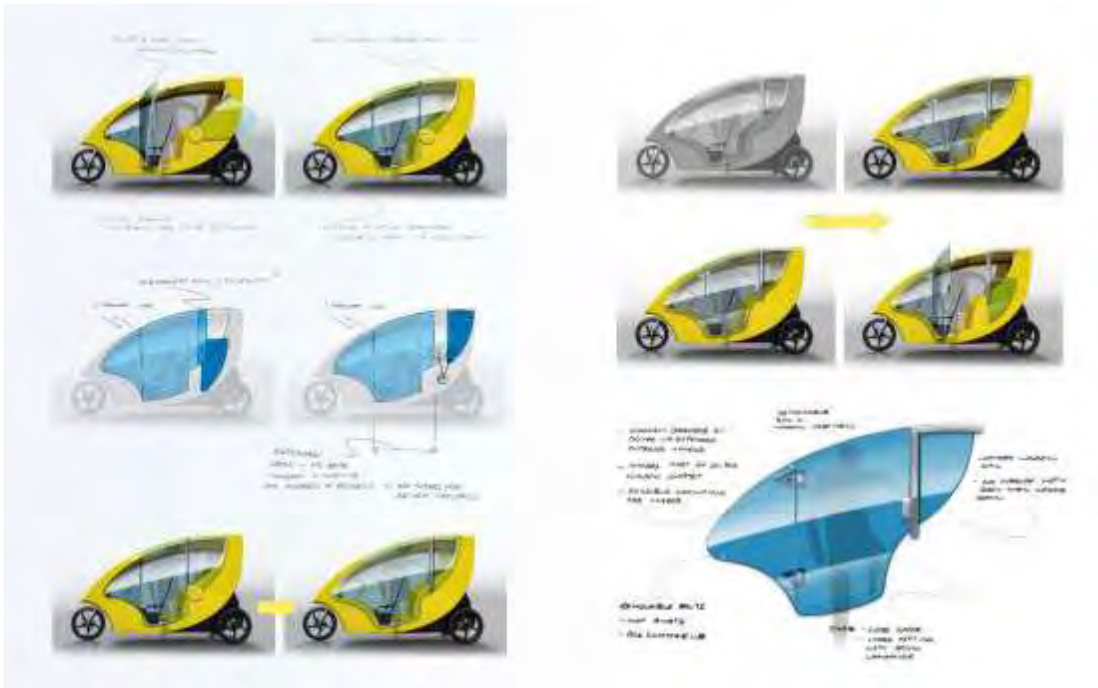


Figure 4.29: Horizontally rotating door concept adjustment (Cassim, 2015)

Figure 4.30: Scissor door concept adjustment (Cassim, 2015)

The benefit of horizontally rotating doors is that they require no familiarising on the part of the occupants; being the most popular form of domestic and automotive door (Yusuff, 2007). Allowing them to open up to nealry 90% also allows for easier ingress and egress . Decreasing the size of the rear window to stop interference with an occupant hand position however meant creating a door that opens further (up to 1.1m) in the lateral direction; potentially infringing on anybody adjacent to the vehicle. This is especially relevant given the tight spaces the vehicle will operate in.

SURFACE ANALYSIS

The side-door Concept MC-B was modelled on the *CATIA V6 Generative Shape Design* and *Freestyle Workbenches,* as referenced from the conceptual design process and the digitized model of the *Mellowcabs* vehicle. The high quality surface modelling structure was created by wireframes and surfaces which were referenced from the digital cab geometry model of the *Second Edition Mellowcab Electric Vehicle*.

Because the shape of the door surface is curved in three dimensions, a *Surfacic* Curvature analysis, Highlight Analysis and Iso-Curvature Analysis had been performed to analyse the overall quality of the door structure and to detect discontinuities in the surface. The Highlight Analysis image to the left indicates discontinuities in the surface structure that needed attention. The image in the middle indicates the repaired discontinuities, and the Highlight and Iso-Curve Analysis image to the right indicates a perfectly consistent and coherent aerodynamic surface.

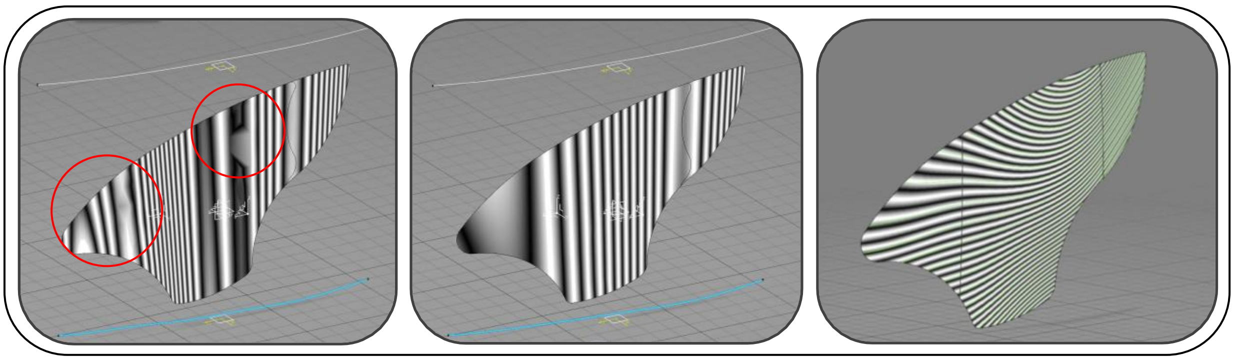


Figure 4.31: Door Surface Analysis (Author, 2015)

MOVEMENT SIMULATION

In terms of the vertical opening scissor doors, the compounded shaped sides of the vehicle would need to be cleared for the doors to operate properly. To validate that the concept could work as proposed, a simulation was done in CATIA to verify that no interference existed between the body and the door (de Vos, 2015).

Figure 4.32: Horizontally rotating door space requirement (Author, 2015)

As expected, if the doors were to rotate forward along the arc of the forward fender, clashes between the door and vehicle body would occur. Through simulating a mechanical linkage it was however found that the scissor action was indeed plausible (Figure 4.33). The linkage acts similarly to those on existing scissor door designs, pushing the door outwards before pivoting upwards.

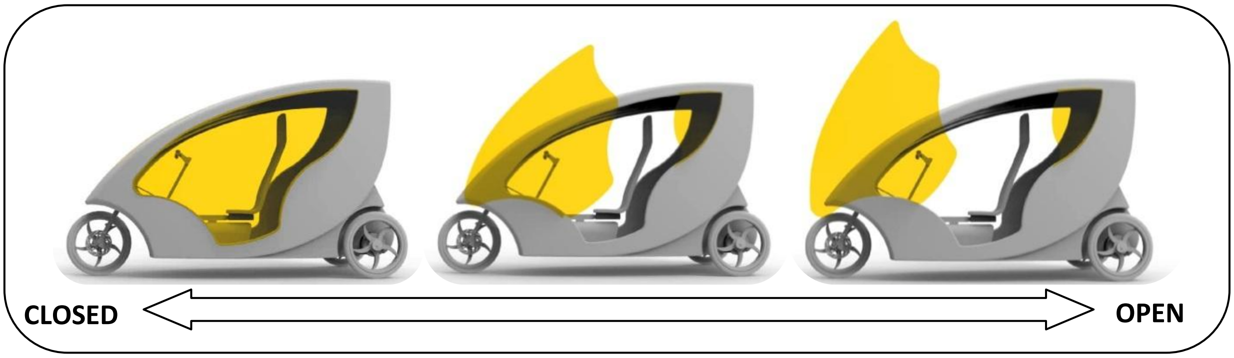


Figure 4.33: Scissor door movement simulation (Author, 2015)

In terms of their usability, vertical scissor doors perform much better in tight spaces; requiring only slightly more space than the width of the door to open fully REF. Additionally, with the opening motion set to move through 51. 5 degrees, the entire door pivots out of the way, causing no reduction of space in the area needed for ingress/egress. This angle allows the virtual manikin to complete ingress and egress unimpeded, with zero clashes occurring with the door or rear window (Figure 4.34). This design was thus seen as the logical choice in terms of usability. In addition to this, a subsequent focus group also showed the scissor doors were trendier and suited the style of the vehicle better. The general consensus being that it looked natural, fluent, and not like an ad-on.

Figure 4.34: Scissor door ingress & egress validation (Author, 2015)

VIRTUAL HUMAN FACTOR SIMULATION

This section presents the results gained from a virtual manikin to evaluate the ergonomic ingress and egress motion for passengers of a micro-mobility vehicle. The captured movements were used to drive the digital manikin in CATIA.

Figure 4.35: Captured movements during video analysis, simulated to drive digital manikin in CATIA (Author, 2015)

INGRESS & EGRESS SIMULATION

The chosen ingress and egress motions were based on the findings during the Video Analysis and Usability Study. Similarly visual clearance of the manikin was simulated, and found to have clear vision during ingress and egress (See DVD appendix). Additionally a posture analysis is discussed for the separate ingress and egress motions.

POSTURE ANALYSIS

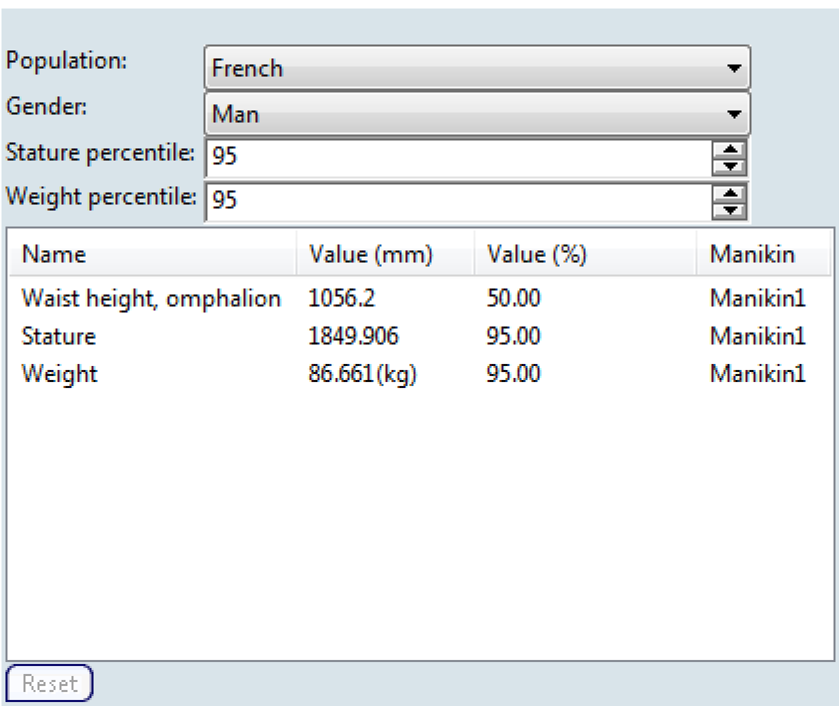
For the context of this thesis a Rapid Upper Limb Assessment (RULA) is used for intuitive posture analysis. Colour coding techniques provide postural information for all segments of the manikin according to the preferred motion zones, which allows that problem areas can be quickly identified. Obtained colour coding are scales from GREEN, YELLOW, ORANGE, to RED; where GREEN indicates good posture, YELLOW indicates good posture with leaning support, ORANGE indicates discomfort or slight strain and suggests to investigate, RED indicates bad posture in need of immediate attention based on the selected metric.

Each subtask presents the analysis of three intermittent body sequences. During the ingress and egress motion, the manikin is not carrying any load; therefore, the load for the study has been set to 0Kg. Additional factors such as arm support for person Leaning, arms working across midline and balance are applied to each sequence during the posture analysis.

<u>95th Percentile French/African Male</u>

Stature: 184.9 cm

Weight: 86.7 kg



Population: French

Gender: Man

Stature percentile: 95

Weight percentile: 95

Name	Value (mm)	Value (%)	Manikin
Waist height, omphalion	1056.2	50.00	Manikin1
Stature	1849.906	95.00	Manikin1
Weight	86.661(kg)	95.00	Manikin1

Reset

Subtask 1 – Entering RULA Analysis

The starting position of the manikin is in the standing posture. Therefore, Subtask 1 starts from a standing posture then emerging into the cab adhering to the three points of contact safety regulations in Section 2.2.6.

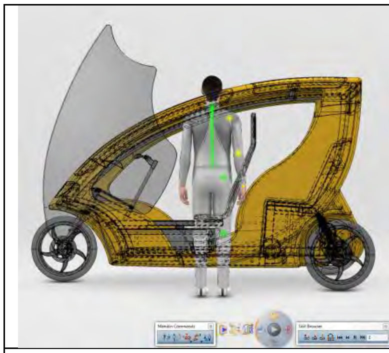
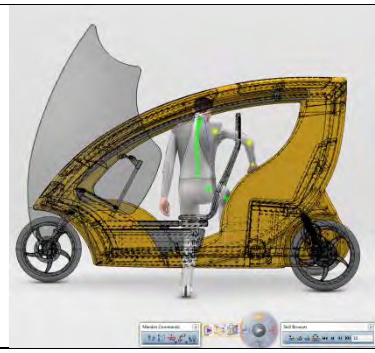
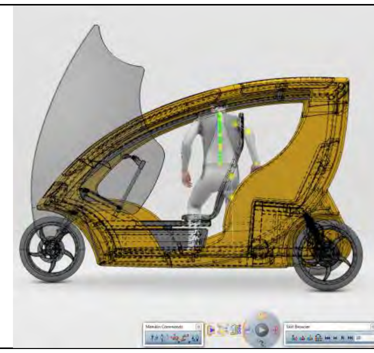
					
Sequence 1.1		**Sequence 1.2**		**Sequence1.3**	
Upper Arm	YELLOW	**Upper Arm**	YELLOW	**Upper Arm**	YELLOW
Forearm	YELLOW	**Forearm**	YELLOW	**Forearm**	YELLOW
Wrist	YELLOW	**Wrist**	YELLOW	**Wrist**	YELLOW
Wrist Twist	YELLOW	**Wrist Twist**	YELLOW	**Wrist Twist**	YELLOW
Neck	GREEN	**Neck**	GREEN	**Neck**	GREEN
Trunk	GREEN	**Trunk**	GREEN	**Trunk**	GREEN
Leg	GREEN	**Leg**	GREEN	**Leg**	YELLOW

Table 4.4: Subtask 1 – Entering Posture analysis

Subtask 2 – Sitting RULA Analysis

During this position the manikin fits his body in a narrow area between the front driver seat and the back passenger seat. The hip is located in the proper seat area such that the posture ends in a sit-ready position in the cab.

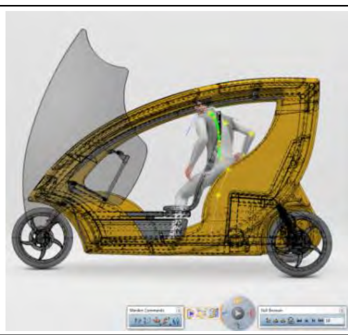
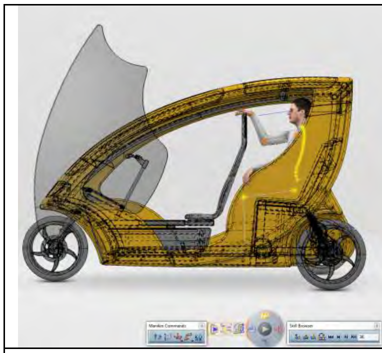
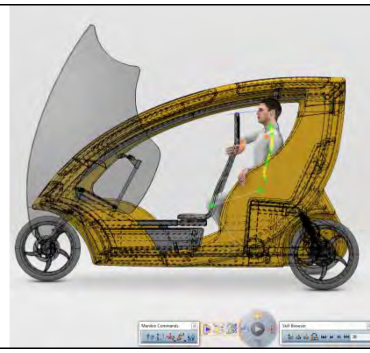
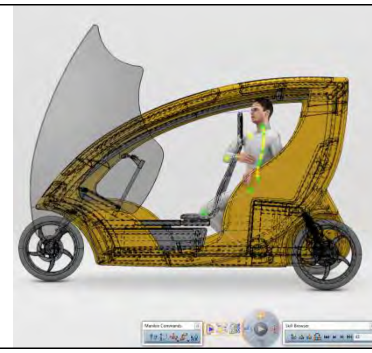
					
Sequence 2.1		**Sequence 2.2**		**Sequence2.3**	
Upper Arm	YELLOW	**Upper Arm**	ORANGE	**Upper Arm**	GREEN
Forearm	YELLOW	**Forearm**	ORANGE	**Forearm**	GREEN
Wrist	YELLOW	**Wrist**	ORANGE	**Wrist**	GREEN
Wrist Twist	YELLOW	**Wrist Twist**	ORANGE	**Wrist Twist**	GREEN
Neck	GREEN	**Neck**	YELLOW	**Neck**	YELLOW
Trunk	GREEN	**Trunk**	YELLOW	**Trunk**	YELLOW
Leg	YELLOW	**Leg**	YELLOW	**Leg**	YELLOW

Table 4.5: Subtask 2 – Sitting Posture analysis

Subtask 3 – Rising RULA Analysis

During this position the manikin gets up and prepares to move out the cab. The hip of the manikin is off the seat while grasping the safety bar.

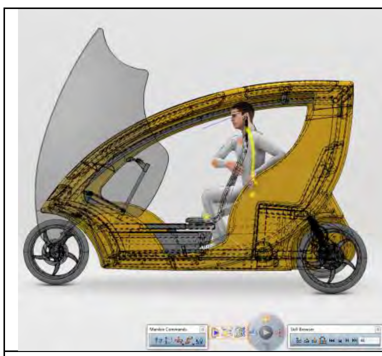
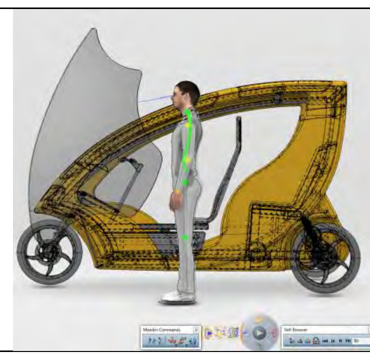
		

	Sequence 3.1	**Sequence 3.2**	**Sequence3.3**
Upper Arm	ORANGE	ORANGE	YELLOW
Forearm	ORANGE	ORANGE	YELLOW
Wrist	ORANGE	ORANGE	YELLOW
Wrist Twist	ORANGE	ORANGE	GREEN
Neck	YELLOW	GREEN	GREEN
Trunk	YELLOW	YELLOW	YELLOW
Leg	YELLOW	GREEN	GREEN

Table 4.6: Subtask 3 – Rising Posture analysis

Subtask 4 – Exiting RULA Analysis

This is the position in which the manikin steps out while exiting the cab. The manikin rotates his body to face the exit and emerges out off the cab.

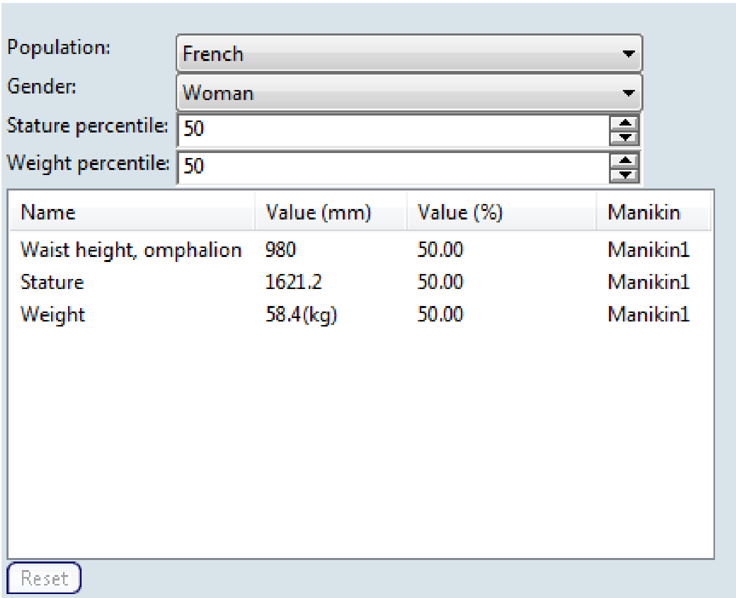
	Sequence 4.1	**Sequence 4.2**	**Sequence 4.3**
Upper Arm	ORANGE	YELLOW	YELLOW
Forearm	ORANGE	YELLOW	YELLOW
Wrist	ORANGE	YELLOW	YELLOW
Wrist Twist	YELLOW	YELLOW	GREEN
Neck	YELLOW	YELLOW	GREEN
Trunk	GREEN	YELLOW	GREEN
Leg	GREEN	YELLOW	GREEN

Table 4.7: Subtask 4 – Exiting Posture analysis

50th Percentile French/African Female

Stature: 162.1 cm

Weight: 58.4 kg



Subtask 1 – Entering RULA Analysis

The starting position of the manikin is in the standing posture. Therefore, Subtask 1 starts from a standing posture then emerging into the cab adhering to the three points of contact safety regulations in Section 2.2.6.

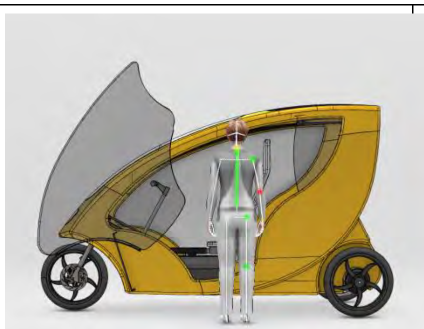
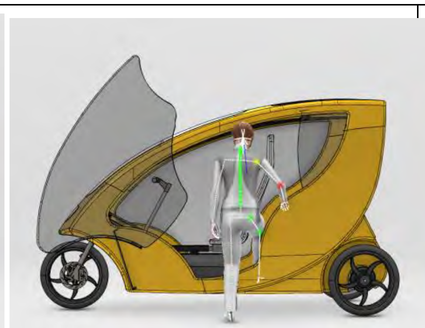
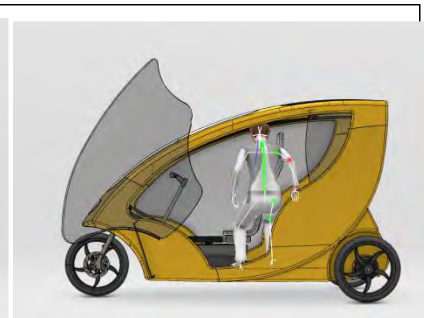
					
Sequence 1.1		**Sequence 1.2**		**Sequence1.3**	
Upper Arm	YELLOW	**Upper Arm**	YELLOW	**Upper Arm**	YELLOW
Forearm	YELLOW	**Forearm**	YELLOW	**Forearm**	YELLOW
Wrist	YELLOW	**Wrist**	YELLOW	**Wrist**	YELLOW
Wrist Twist	YELLOW	**Wrist Twist**	YELLOW	**Wrist Twist**	YELLOW
Neck	GREEN	**Neck**	GREEN	**Neck**	GREEN
Trunk	GREEN	**Trunk**	GREEN	**Trunk**	GREEN
Leg	GREEN	**Leg**	GREEN	**Leg**	YELLOW

Table 4.8: Subtask 1 – Entering Posture analysis

Subtask 2 – Sitting RULA Analysis

During this position the manikin fits his body in a narrow area between the front driver seat and the back passenger seat. The hip is located in the proper seat area such that the posture ends in a sit-ready position in the cab.

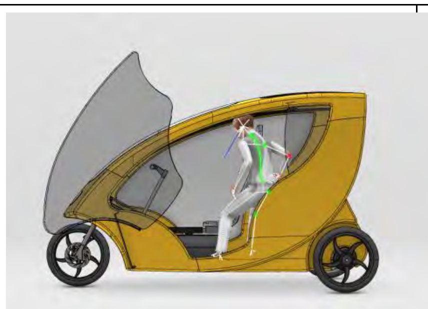
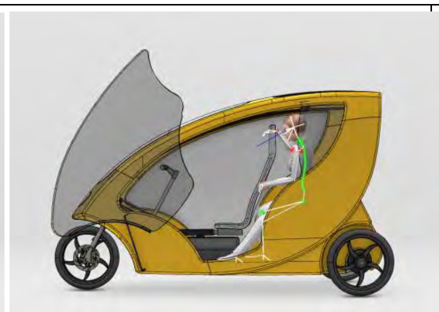
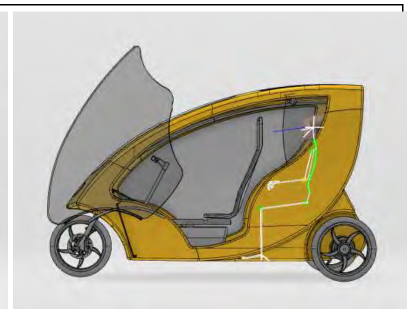
					
Sequence 2.1		**Sequence 2.2**		**Sequence2.3**	
Upper Arm	YELLOW	**Upper Arm**	ORANGE	**Upper Arm**	GREEN
Forearm	YELLOW	**Forearm**	ORANGE	**Forearm**	GREEN
Wrist	YELLOW	**Wrist**	ORANGE	**Wrist**	GREEN
Wrist Twist	YELLOW	**Wrist Twist**	ORANGE	**Wrist Twist**	GREEN
Neck	GREEN	**Neck**	YELLOW	**Neck**	YELLOW
Trunk	GREEN	**Trunk**	YELLOW	**Trunk**	YELLOW
Leg	YELLOW	**Leg**	YELLOW	**Leg**	YELLOW

Table 4.9: Subtask 2 – Sitting Posture analysis

Subtask 3 – Rising RULA Analysis

During this position the manikin gets up and prepares to move out the cab. The hip of the manikin is off the seat while grasping the safety bar.

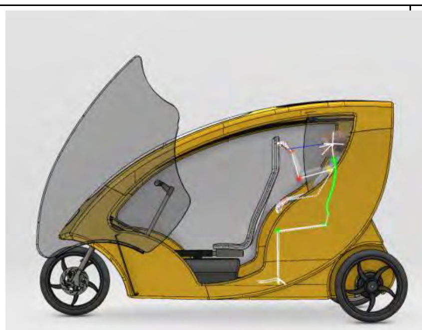
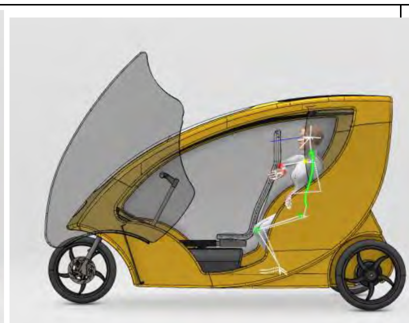
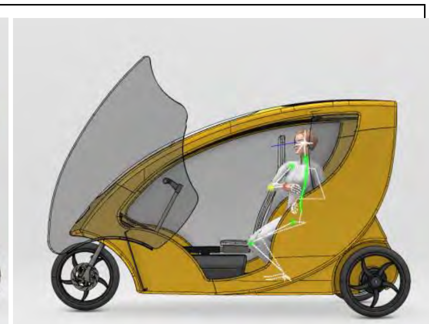
					
Sequence 3.1		**Sequence 3.2**		**Sequence3.3**	
Upper Arm	ORANGE	**Upper Arm**	ORANGE	**Upper Arm**	YELLOW
Forearm	ORANGE	**Forearm**	ORANGE	**Forearm**	YELLOW
Wrist	ORANGE	**Wrist**	ORANGE	**Wrist**	YELLOW
Wrist Twist	ORANGE	**Wrist Twist**	ORANGE	**Wrist Twist**	GREEN
Neck	YELLOW	**Neck**	GREEN	**Neck**	GREEN
Trunk	YELLOW	**Trunk**	YELLOW	**Trunk**	YELLOW
Leg	YELLOW	**Leg**	GREEN	**Leg**	GREEN

Table 4.10: Subtask 3 – Rising Posture analysis

Subtask 4 – Exiting RULA Analysis

This is the position in which the manikin steps out while exiting the cab. The manikin rotates his body to face the exit and emerges out off the cab.

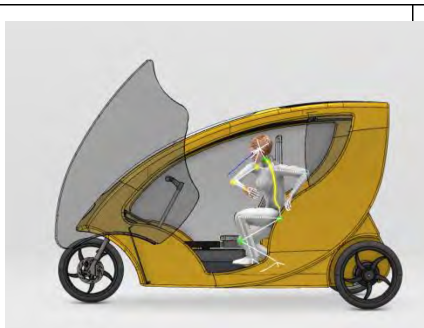
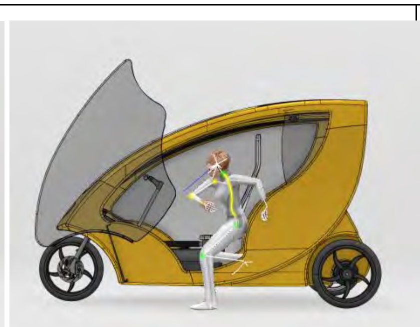
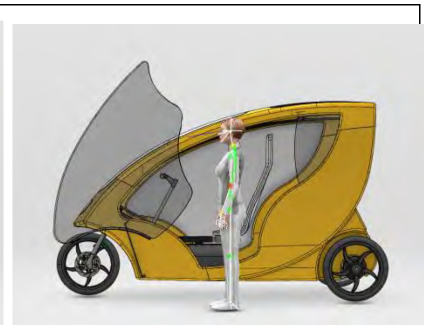
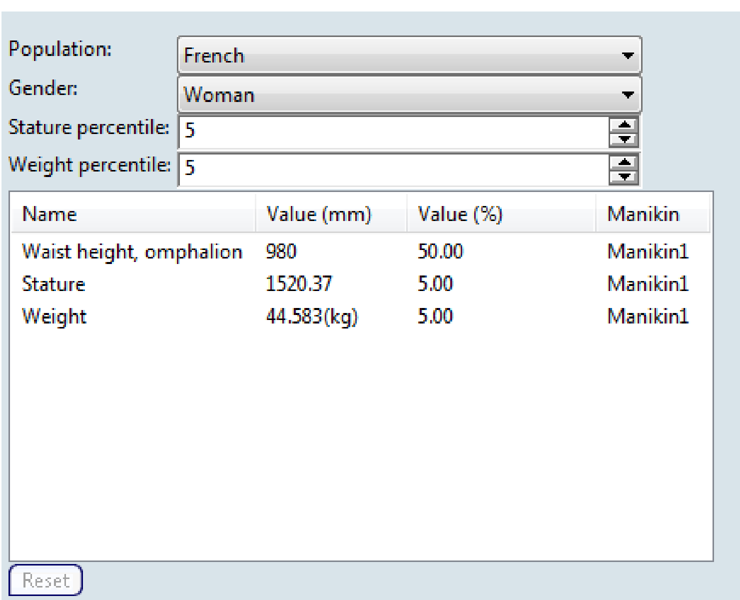
					
Sequence 4.1		**Sequence 4.2**		**Sequence 4.3**	
Upper Arm	ORANGE	**Upper Arm**	YELLOW	**Upper Arm**	YELLOW
Forearm	ORANGE	**Forearm**	YELLOW	**Forearm**	YELLOW
Wrist	ORANGE	**Wrist**	YELLOW	**Wrist**	YELLOW
Wrist Twist	YELLOW	**Wrist Twist**	YELLOW	**Wrist Twist**	GREEN
Neck	YELLOW	**Neck**	YELLOW	**Neck**	GREEN
Trunk	GREEN	**Trunk**	YELLOW	**Trunk**	GREEN
Leg	GREEN	**Leg**	YELLOW	**Leg**	GREEN

Table 4.11 Subtask 4 – Exiting Posture analysis

5th Percentile French/African Female

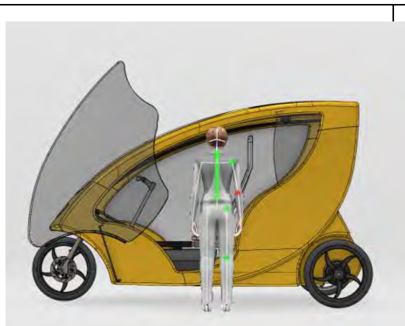
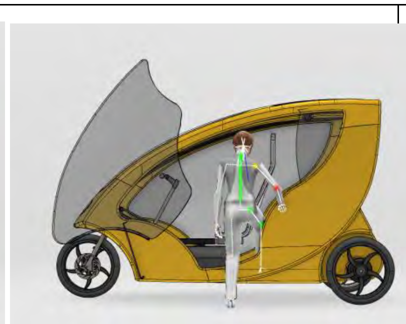
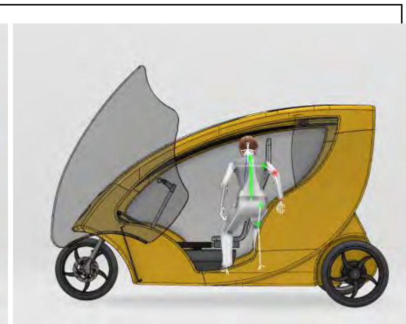
Stature: 152.0 cm

Weight: 44.6 kg



Subtask 1 – Entering RULA Analysis

The starting position of the manikin is in the standing posture. Therefore, Subtask 1 starts from a standing posture then emerging into the cab adhering to the three points of contact safety regulations in Section 2.2.6.

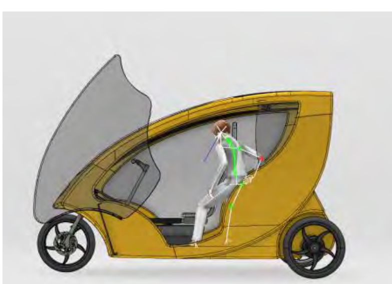
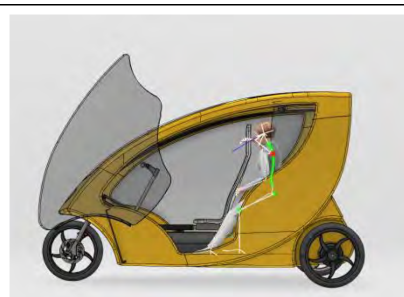
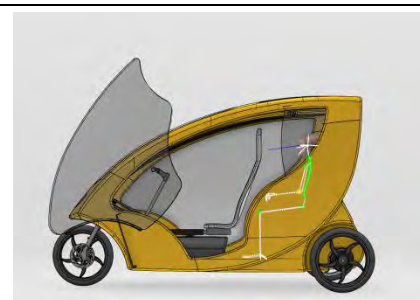
		
Sequence 1.1	**Sequence 1.2**	**Sequence1.3**

	Sequence 1.1	Sequence 1.2	Sequence1.3
Upper Arm	YELLOW	YELLOW	YELLOW
Forearm	YELLOW	YELLOW	YELLOW
Wrist	YELLOW	YELLOW	YELLOW
Wrist Twist	YELLOW	YELLOW	YELLOW
Neck	GREEN	GREEN	GREEN
Trunk	GREEN	GREEN	GREEN
Leg	GREEN	GREEN	YELLOW

Table 4.12: Subtask 1 – Entering Posture analysis

Subtask 2 – Sitting RULA Analysis

During this position the manikin fits his body in a narrow area between the front driver seat and the back passenger seat. The hip is located in the proper seat area such that the posture ends in a sit-ready position in the cab.

		
Sequence 2.1	**Sequence 2.2**	**Sequence2.3**

	Sequence 2.1	Sequence 2.2	Sequence2.3
Upper Arm	YELLOW	ORANGE	GREEN
Forearm	YELLOW	ORANGE	GREEN
Wrist	YELLOW	ORANGE	GREEN
Wrist Twist	YELLOW	ORANGE	GREEN
Neck	GREEN	YELLOW	YELLOW
Trunk	GREEN	YELLOW	YELLOW
Leg	YELLOW	YELLOW	YELLOW

Table 4.13: Subtask 2 – Sitting Posture analysis

Subtask 3 – Rising RULA Analysis

During this position the manikin gets up and prepares to move out the cab. The hip of the manikin is off the seat while grasping the safety bar.

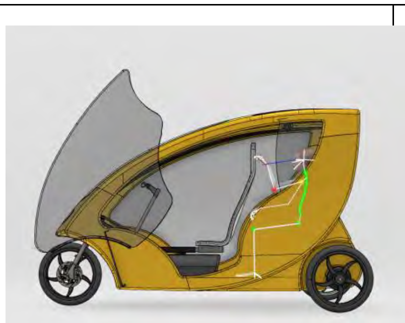
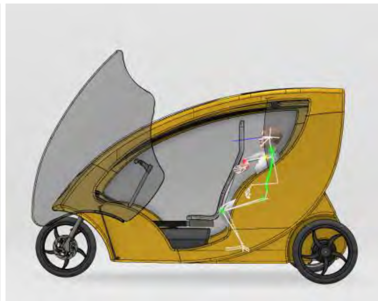
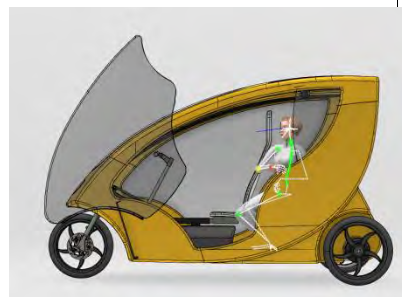
					
Sequence 3.1		**Sequence 3.2**		**Sequence3.3**	
Upper Arm	ORANGE	**Upper Arm**	ORANGE	**Upper Arm**	YELLOW
Forearm	ORANGE	**Forearm**	ORANGE	**Forearm**	YELLOW
Wrist	ORANGE	**Wrist**	ORANGE	**Wrist**	YELLOW
Wrist Twist	ORANGE	**Wrist Twist**	ORANGE	**Wrist Twist**	GREEN
Neck	YELLOW	**Neck**	GREEN	**Neck**	GREEN
Trunk	YELLOW	**Trunk**	YELLOW	**Trunk**	YELLOW
Leg	YELLOW	**Leg**	GREEN	**Leg**	GREEN

Table 4.14: Subtask 3 – Rising Posture analysis

Subtask 4 – Exiting RULA Analysis

This is the position in which the manikin steps out while exiting the cab. The manikin rotates his body to face the exit and emerges out off the cab.

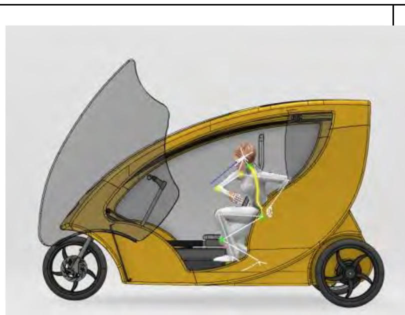
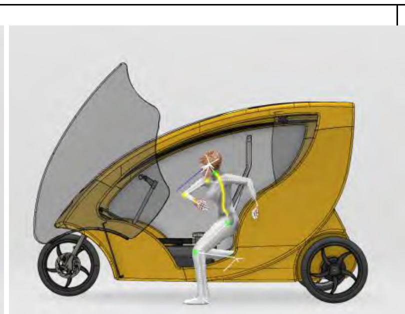
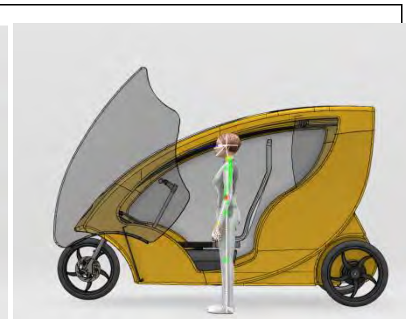
					
Sequence 4.1		**Sequence 4.2**		**Sequence 4.3**	
Upper Arm	ORANGE	**Upper Arm**	YELLOW	**Upper Arm**	YELLOW
Forearm	ORANGE	**Forearm**	YELLOW	**Forearm**	YELLOW
Wrist	ORANGE	**Wrist**	YELLOW	**Wrist**	YELLOW
Wrist Twist	YELLOW	**Wrist Twist**	YELLOW	**Wrist Twist**	GREEN
Neck	YELLOW	**Neck**	YELLOW	**Neck**	GREEN
Trunk	GREEN	**Trunk**	YELLOW	**Trunk**	GREEN
Leg	GREEN	**Leg**	YELLOW	**Leg**	GREEN

Table 4.15: Subtask 4 – Exiting Posture analysis

RESULTS FOR INGRESS

To analyze the current design case – Subtasks 1 and 2 – are selected as the proposed ingress movement. The ingress movement begins in Sequence 1.1 with the manikin standing to face the open cab door geometry. The spinal and leg area indicated good posture with GREEN and the arm area shows YELLOW which could indicate the manikin starting to lift the arm towards the cabs outer door frame. In Sequence 1.2 the manikin reaches the outer door frame with his right hand while simultaneously stepping in with his right leg. The spinal and leg posture displayed GREEN which is a good indication that the step height is acceptable, accessible and comfortable. However the arm to wrist area displayed YELLOW which merely indicates that the arm is supporting the person leaning thus experiencing some load for good posture.

During Sequence 1.3 ingress involves the left foot stepping of the ground emerging the body to manoeuvre through the door geometry such that both feet are placed inside the cab. This is to adhere to the contact safety regulations in Section 2.3. Sequence 1.3 displayed YELLOW for both the arm to wrist are and leg are, which indicates that the manikins body weight and balance is being supported by the arm while the knee and leg are experiencing load and torque. The upper neck to trunk are displayed GREEN, while sections of the lower spine trunk displayed areas of YELLOW, indicating the back is slightly bended. Both the leg and spinal colour coding indicates that the manikin is crouching to fit inside the cab during this sequence.

In the final step of the ingress, the right hand is placed on the driver seat head rest, while the body rotates in front of the passenger seat placing the feet perpendicular to the seat before the passenger sits down. In Sequence 2.2, the spinal and leg areas displayed YELLOW, which indicates the rotating action and the support of the body weight before the manikin sits down. The arm to wrist area displayed ORANGE, which indicates discomfort to the manikins' arm, as the driver seat head rest might be too high to reach.

RESULTS FOR EGRESS

Egress movement starts from the sitting position. In Sequence 3.1 the manikin is placing his left hand on the outer door frame while similarly placing his right hand on the driver seat head rest. The spinal and leg areas displayed YELLOW as the lumbar support prepares to rise, while the arm area displayed ORANGE, which indicates again that the headrest is too high for the manikin to reach, showing discomfort.

In Sequence 3.2 the manikin is sliding forward along the seat toward the front. The arm area again displayed ORANGE, indicating that the driver seat is too close thus forcing the arm of the manikin to manoeuvre in an uncomfortable position. As the arm clears the driver seat while the body rotates towards the door geometry in Sequence 3.3, the analysis displayed GREEN and YELLOW indicating no major discomfort to the posture.

Sequence 4.1 initiates the final step of egress as the left foot starts to approach the cab exit. The arm area displays ORANGE, suggesting that the driver seat could possibly be to close that causes discomfort during avoidance. The leg and spinal area displayed YELLOW, indication of the force or torque for the push up and out manoeuvre (exit). Sequence 4.2 simulates the right foot stepping off the cab floor; the left hand is supporting the body on the outer door frame, whilst the left leg supports the body weight and identifies the location. All indications display YELLOW, which indicates that the manikins' body weight and balance is being supported by the arm while the knee and leg are experiencing load and torque. In the final sequence, after the manikin steps out, a comfortable standing position is taken (Sequence 4.3).

SUMMARY

This section had presented the posture analysis results gained from a virtual manikin to evaluate the ergonomic ingress and egress motion for passengers of a locally based micro-mobility vehicle, the *Second Edition Mellowcab Electric Vehicle*.

The biggest difference between ingress and egress with a simple task like walking is that ingress and egress motion interacts with geometries. While a person could walk without any geometry, ingress and egress motion needs to have an object to get in and out of. During ingress and egress motion, a person cannot strike the objects. Each frame and individual component of the object would be an obstacle to avoid. Therefore, collision avoidance was considered.

During the virtual simulation, the manikin successfully accomplished all the ingress and egress movements. This indicated that the new *Second Edition Mellowcab Electric Vehicle* meets the required occupant packaging standards, as a person would be able to successfully enter and exit the vehicle. Additionally, the manikin was able to accomplish all the ingress and egress tasks with the proposed "Scissor Door" concept MC-B at its maximum opened position. There are no clashes detected that hinders the manikins ingress and egress movement whilst he passes the bottom-door edge, and the side-back window.

However, concerns are raised with the driver seat, as it interferes or causes discomfort to the passenger manikin entering and exiting the vehicle. The driver seat could be adjusted forward away from the passenger seat to allow for an easier rotating action, and more space in the passenger cabin. Additionally, the driver seat back rest is leaning excessively towards the passenger seats. Adjusting this degree of angle will not only benefit for more manoeuvrability in the passenger cabin space, but serve better seating ergonomics for the driver. Finally, the driver seat head rest was found to be used as a support structure and determined as a hand input, yet the results indicate that it is too high for a comfortable reach, and propose the addition of hand rails.

Although the higher door sill needed more strain from the manikin to exert such to lift his feet over the sill, it did not affect the ease of lifting his legs in or out of the vehicle. However the door-sill should be well rounded and have a smooth surface with no sharp edges to permit people's feet to easily glide over. In the context of this thesis, factors to consider are passenger view (inside and outside), door entry and exit, rear passenger clearance and spaciousness, vibration and noise, and trunk space.

4.3.3. THIRD PHASE: DOOR DESIGN DEVELOPMENT

While the previous section validates that vertical opening ‘scissor’ doors are viable and do not physically impede commuters, it does not provide feedback in terms of user perception or effort. For this a mock-up based on the concept in figure 4.36 was constructed to gain user input. This information was then utilised to further optimise the design in terms of Universal Design.

As the commuter’s initial point of contact, the vehicle door handles served as the starting point for further design development. Designed to consider universal design from the outset, early concepts focused on providing intuitive usage, low effort and sufficient clearance for user’s hands (based on anthropometrics data in figure 4.37) (learneasy, 2015).

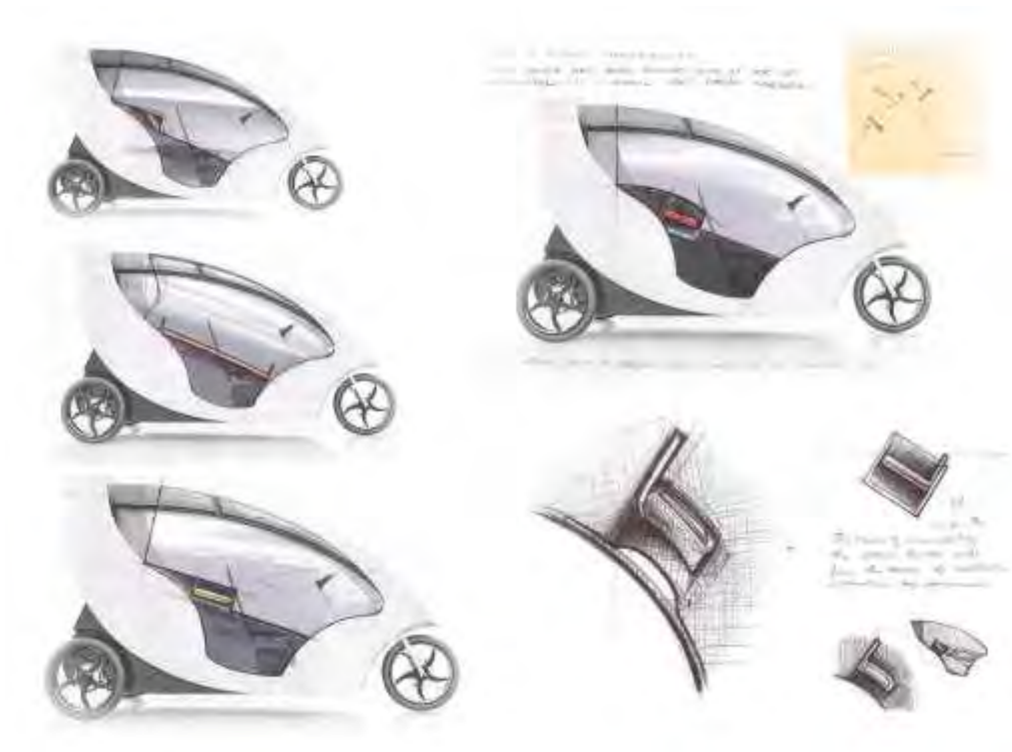
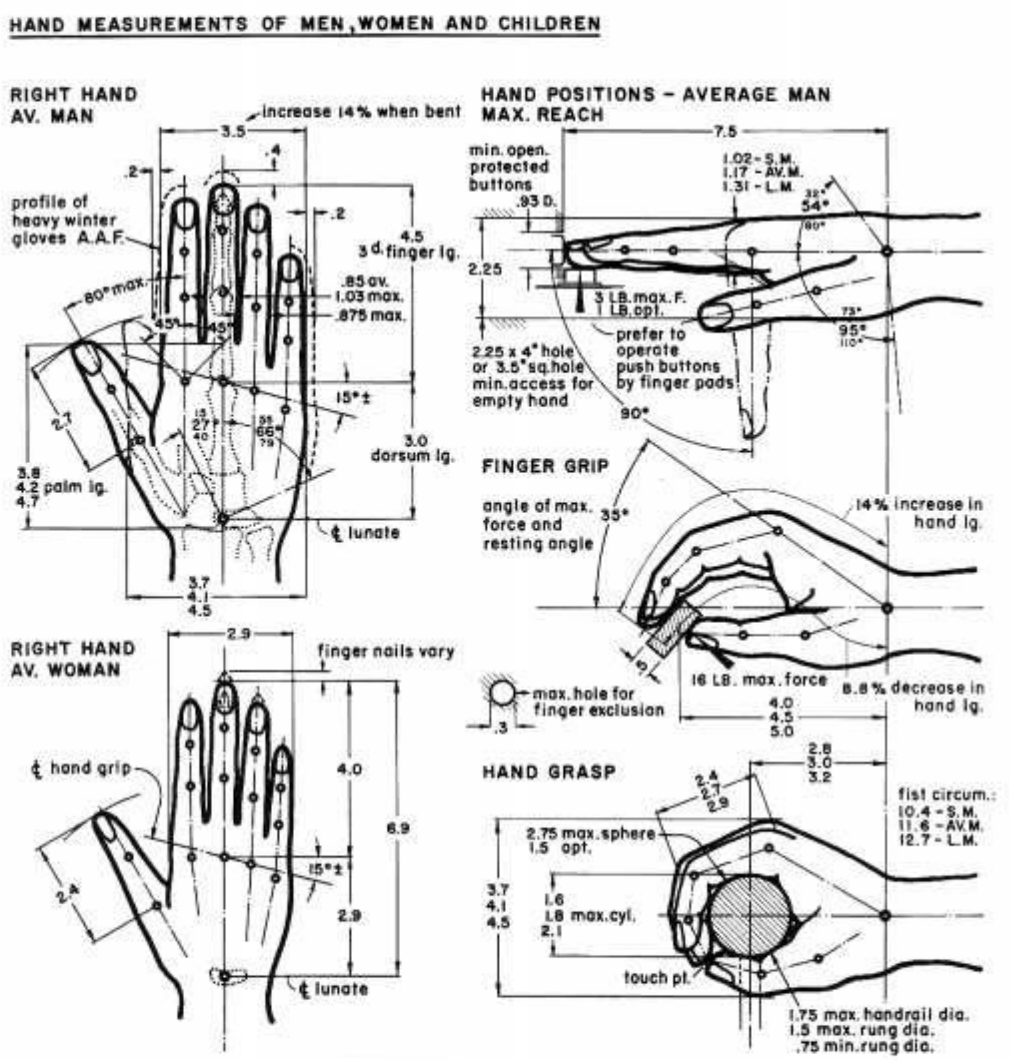


Figure 4.36: Initial door handle concepts (Cassim, 2015)



HAND DATA	MEN			WOMEN			CHILDREN			
	2.5 % tile	50. % tile	97.5 % tile	2.5 % tile	50. % tile	97.5 % tile	6 yr.	8 yr.	11 yr.	14 yr.
hand length	6.8	7.5	8.2	6.2	6.9	7.5	5.1	5.6	6.3	7.0
hand breadth	3.2	3.5	3.8	2.6	2.9	3.1	2.3	2.5	2.8	—
3d. finger lg.	4.0	4.5	5.0	3.6	4.0	4.4	2.9	3.2	3.5	4.0
dorsum lg.	2.8	3.0	3.2	2.6	2.9	3.1	2.2	2.4	2.8	3.0
thumb length	2.4	2.7	3.0	2.2	2.4	2.6	1.8	2.0	2.2	2.4

Figure 4.37: Hand Anthropometric Data (Learneasy, 2015)

USER TESTING AND VALIDATION

Initial user testing consisted of a simulated side approach and vehicle entry. Two handle types with differing heights were tested by participants ranging from 30 to 69 years old.

Handle A was placed at 990mm above ground level as this was within an acceptable range for most humans (Designingforhumans, 2009). Figure 87 shows a wheelchair bound 5th percentile US adult female, a 5th percentile Japanese adult female and a 95th percentile US adult male converging at this height. The second handle was placed slightly lower at 910mm. This was done to take into account the pivot of the handle as well as the fact that taller individuals might be able to bend slightly; whereas older and shorter people or those with disabilities might struggle more. While both handles performed well and allowed the door to be opened with relative ease some issues did arise.

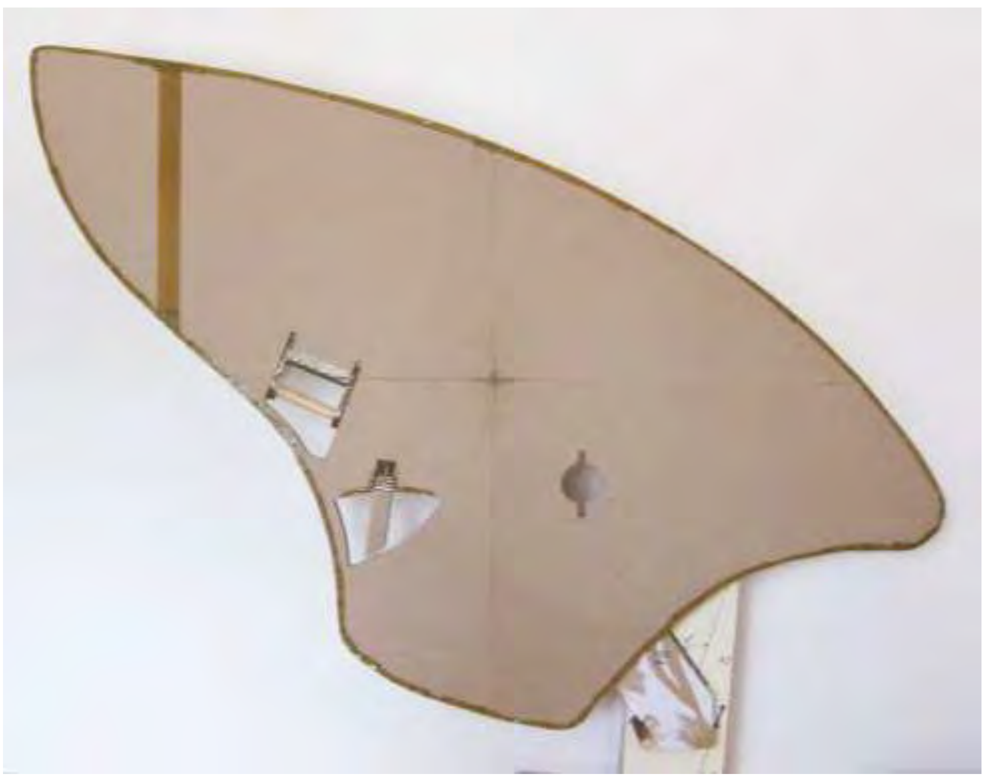


Figure 4.38: Door Mock-up (Cassim, 2015)

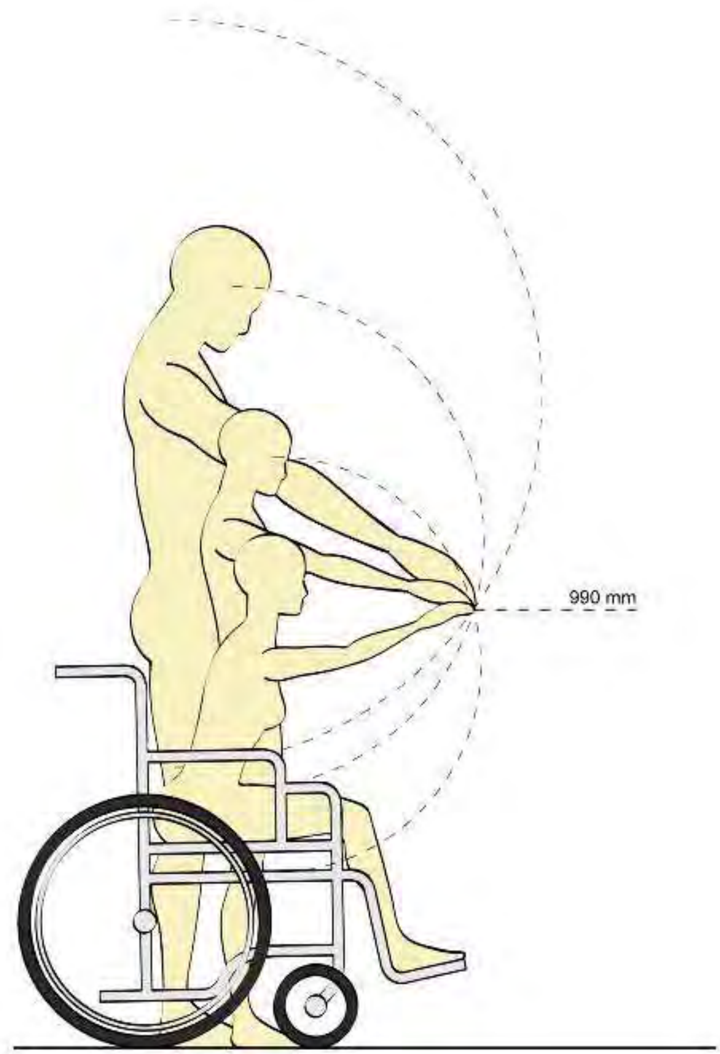


Figure 4.39: Aggregate Handle Height, (Designingforhumans, 2009)

HANDLE A

During initial familiarisation it was found that while affording the correct pulling action, the design was ambiguous in terms of hand position; one participant not being able to decide whether to use an overhand or underhand approach (Figure 4.40). Participants tended to keep pulling the handle outwards instead of performing a lifting action; while also holding onto it throughout its 51.5 degree movement (Figure 4.41). It thus did not afford the desired usage. Additionally it was commented that the handle placed some stress on both the wrist and shoulder, even though most found it easy to use (Figure 4.42). Further investigation concluded this was in part due to the handle being too high. Some clearance issues also existed between one participant's knuckles and the door pane, potentially causing an obstruction or injury for those with bigger hands or anyone wearing gloves.

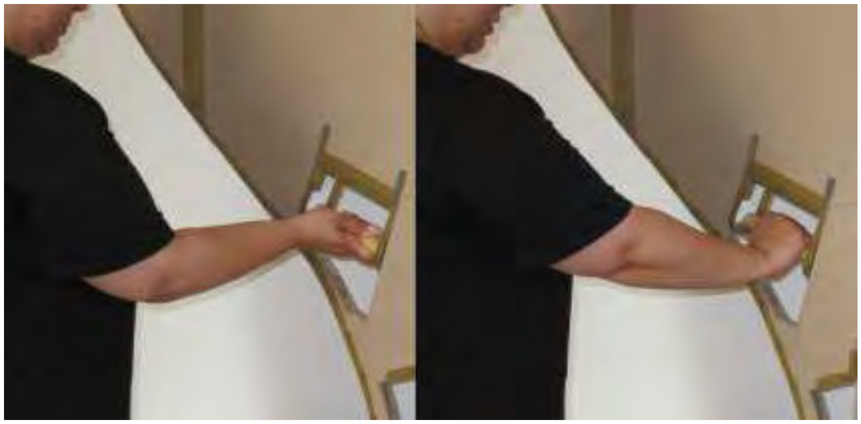


Figure 4.40: Poor Affordance (Cassim, 2015)

Figure 4.41: Joint Stress (Cassim, 2015)

Figure 4.42: Poor Affordance (Cassim, 2015)

HANDLE B

Handle B cause no obvious issues regarding affordances, with all participants finding its usage more intuitive than that of handle A. It correctly afforded an initial pulling action which translated into a lifting action once the handle came closer to the perpendicular. No issues in terms of hand space were reported (Figure 4.43).


Figure 4.43: Handle B – Good Affordances (Cassim, 2015)

While the mock-up was outfitted with springs to mimic the gas strut, setting them to lift the door automatically proved impractical. They were thus set to assist the door once on the move. Ideally handle B should allow the door to lift (via the strut) when 45 degrees are reached. This means at least half of any force exerted on the handle by the user would be working in the upwards direction. Even though no complaints were voiced; some articulation of the wrist can be seen. This however should be lessened considerably when the maximum handle opening angle is reduced to approximately 45 degrees.

One unexpected result during testing was the use of the lower rear part of the door as a support when simulating vehicle entry (Figure 4.44).

Figure 4.44: Affording door edge as hand grip/ push off (Cassim, 2015)

Additional tests were conducted to determine the performance of the door and handles in tight space conditions. Approaches from both the left and right were simulated; the space between the wall and the door set at 0.5m (Figure 4.45). Neither handle performed particularly well, with particularly handle A cramping the tester for space. Handle B was still preferred by participants, although it was recommended that the handle be made smaller (Figure 4.46).

Figure 4.45: Simulated front and rear tight space entry (Cassim, 2015)


Figure 4.46: Poor tight space performance (Cassim, 2015)

DOOR HANDLE DESIGN

To improve usability, the door handle design and action were further simplified to lower wrist articulation and keep the wrist in a more neutral position. This further accommodates possible reduced dexterity caused by cold or other conditions.

Given the size of the handles tested, both afforded what is known as a power grip (Hadler, et.al, 1978). As will be explained in a subsequent section however, this will not necessarily be needed for comfortable operation of the door. It was thus decided to impose a combination of a pinch grip, side grip (as one holds a Smart Phone) and the motion of Handle B.

The length of the handle was also reduced from 15cm down to 10 (from the bottom to the pivot point) (Figure 94). This still allows for the usage of 5 fingers, with 4 on the lever and the thumb against the body. Thumb indentations should be placed on the acrylic pane to afford the desired use.

The width was increased to dissuade using a power grip (which puts unnecessary strain on the wrist) and to improve finger location. The bottom of handle was rounded to afford safe usage if the users chooses to utilise it in such a manner. A roughened texture on the back is proposed to prevent the hand slipping from the handle when opening.

The door grip is designed to afford two action; a pulling motion which allows the door to pop out the required distance before a slight lift action rotates it upwards and forwards (a strut attached to the frame providing the power). The handle height was also set at that of the second handle iteration (handle - B), as participants found it easier to use during testing. The aim was to design a handle that is both intuitive and physically easy to use.

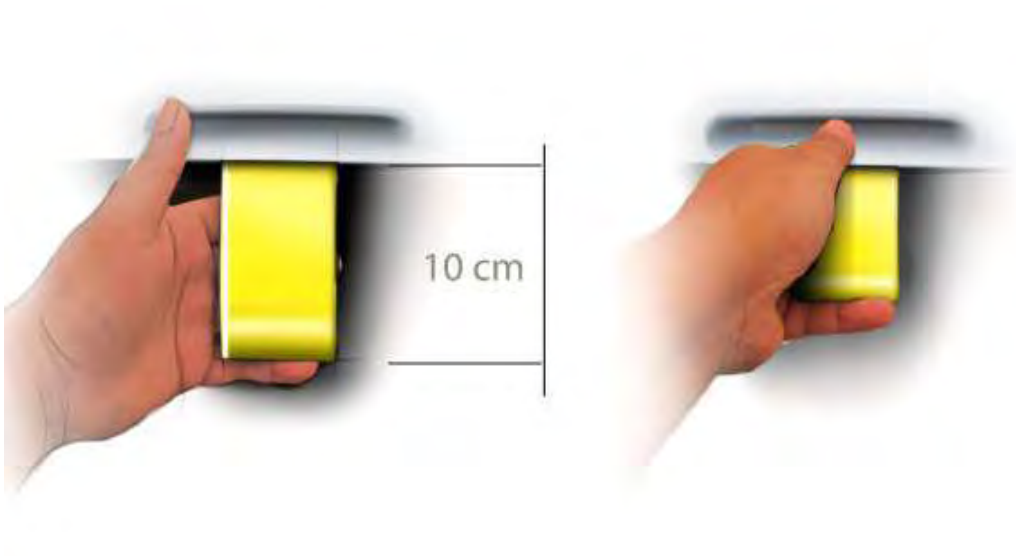


Figure 4.47: Revised door handle design (Cassim, 2015)

TRANSPARENT OUTER PANE: MATERIAL SELECTION

While the door handle is the first point of contact, much of the effort the user exerts will depend on other parts such as the strut mechanism in the subsequent section. The design of this is largely dictated by the desired motion as well as the weight of the door. In considering material for the transparent outer pane, safety glass was ruled out as its mass would be unnecessarily high for a vehicle meant to be efficient (GTS, 2015).

Hard coated polycarbonates were considered, however forming them into the requisite shape would be problematic; affecting both manufacturability and clarity, which affects visibility (excelite, 2015). Uncoated polycarbonates on the other hand would scratch too easily, limiting their usability in such a high traffic application.

After further research and discussion with designer David Robertson (Robertson, 2015), plexiglass@RESIST-75 acrylic was settled on as a suitable material. It does not need a protective coating which means clarity is retained during manufacture. While the NRCS provides no regulations limiting side door design of L2-class vehicles, the material has the same impact resistance as Lexan polycarbonate; meeting EU regulations for motorcycle front screens. It also has typical acrylic benefits such as low scratch resistance and good solar absorption, lessening thermal stresses in the cabin (Appendix H). Consulting Perspex's acrylic design guides for acrylic glazing a 5mm single pane should provide the required stiffness and impact strength (Appendix I).

DOOR OPENING MECHANISM

Based on earlier simulations and user feedback, a hinging system was designed in concert with Engineer Gerry Banda (Banda, 2015). While this mechanism will solely be operated by the driver, its design directly affects the actions and amount of effort required by passengers to open the door. (From the driver's perspective) the lever is initially pulled away from the door, rotating through approximately 11, 5 degrees. This pushes the door outwards by approximately 20mm; moving the latch clear from its attachment pin while keeping the door in the outward position via an internal spring (Figure 4.48). From here a gas strut pushes the door upwards with little user assistance required. The curved arm and pivot then allows this upwards motion to be converted into a forwards rotating 'scissor' motion. This continues until the door mechanism completes its 51.5 degrees of motion and is considered fully open (Figure 4.49).

Figure 4.48: Door Opening Mechanism (Banda, 2015)

Due to the nature of vertical opening doors, the gas strut will be relied upon to overcome the effects of gravity; assisting the user and reducing the effort required to open and close the door. In all the mechanism weights approximately 5kg, the main parts being manufactured from a steel alloy. It has been designed in such a way as to still allow operation even in the event of gas strut failure; with the mechanism attachment point to the door being close to its centre of gravity. This allows the door to be opened with little effort, even without the strut.

Figure 4.49: Mechanism movement simulation (Banda, 2015)

LATCH DESIGN

Directly affecting the motion and effort required when operating the door handles are the door latches. These are important as they keep the doors closed when the vehicle moves; especially when accelerating laterally. Electronic solenoid mechanisms were considered however these run the risk of becoming inoperable if the vehicle were to run out of power; providing no redundancy in the case of failure. Magnets were also considered, however the need to keep the door shut while cornering works in opposition to providing a low effort opening action; opposing universal design principles.

According to the ADA, doors should require no more than 22, 2 N of force to open (ADA National Network, 2015). Utilising a cable operated mechanism means that the force required is dictated and can be set by the latch return spring (Figure 4.50). This can be made much less than the force required to open the door as it only needed to rotate the latch ring. Any failure of the spring will still allow the door to open; while failure of the passenger side latch cable means the door can still be opened via the driver's handle.

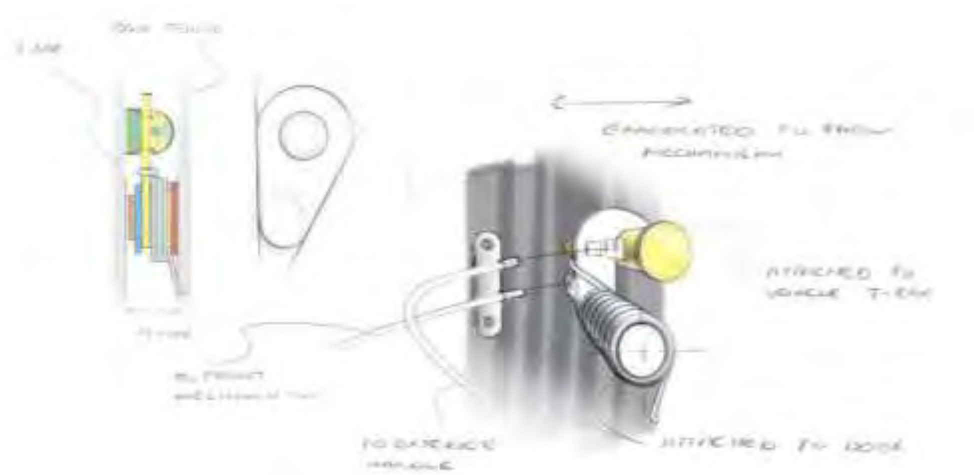


Figure 4.50: Door latch design proposal (Author, 2015)

DOOR SEALING AND FRAME DESIGN

Various sealing methods were discussed with designer Naeem Cassim and engineer Gerry Banda (Cassim, 2015) (Banda, 2015). Initial concepts included either a plastic bead running along the entire aperture of the side opening or altering the vehicle body to create a sealing groove (Figure 4.51). The first proposal was discarded as it increases the step in height and sill width; potentially increasing the chances of slipping. It would also take away head clearance upon entry; important as the vehicle is already limited in this regard. The second proposal would constitute a rather large change to body moulds which would be prohibitively expensive and outside the limitations set by this paper. The shape of the groove along the upper rail would also promote water entering the cabin via the coanda-affect. Any sealing that takes place was thus isolated to the door itself. A moulded carbon fibre frame with rubber seal insert running along its entirety was proposed. The rightmost solution in figure 99 was discussed with Engineer Jeff Ball (Ball, 2015) whom advised against such a complex frame shape as it would be problematic and expensive to mould from carbon fibre. It was suggested that a flat frame with a separate sealing bead; fitting either directly to or on top of the carbon frame be used. This allows the frame to be manufactured in the same way as the body; applying a common P or D shaped foam extrusion to keep out water. Many of these come with adhesive backing already attached (eagetgroup, 2015).

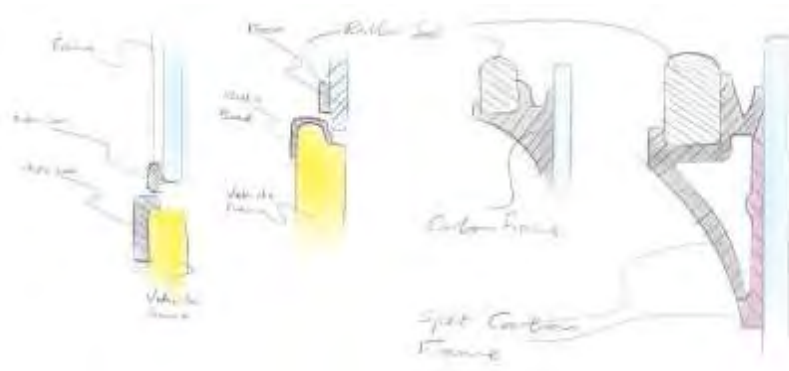


Figure 4.51: Door sealing design development (Cassim, 2015)

Other than the above, frame design is dictated primarily by the positioning of the proposed door lifting mechanism, door handle and latch position, as well as the desired aesthetics. Several concept iterations were put to a subsequent focus group (Figure 4.52).

Figure 4.52: Door frame design concepts (Cassim, 2015)

4.3.4. FOURTH PHASE: DESIGN DEVELOPMENT OF USABILITY RELATED ADAPTATIONS

In a follow up meeting with the initial co-design group, the primary function of the windows either side of the commuter seating area was discussed. It was concluded that in addition to providing enough ventilation for short journeys, it allows the doors size to be reduced; reducing the physical effort required for opening, as well as lowering its total height in the open position. No need existed for a fully functioning window with winding mechanism. Pop-out windows were considered, but discarded for being prone to linkage breakage, being awkward to use and limited in functionality given the previously mentioned drawbacks.

As was found while conducting research, air distribution should be done in such a way that incoming air is blended as smoothly as possible with interior air. Additionally, when referring back to aerodynamic data, one can see that a large low pressure area forms directly behind the vehicle. It was decided to explore a proposal similar to the fabric wind deflectors available for the BMW C1, combined with a louvered rear window. This will create passive ventilation by sucking air through the vehicle when it is on the move. The fabric will be relied upon to diffuse airflow so as to prevent a draught form forming next to the commuter's head (Figure 4.53).

In consultation with Industrial Designer Caleigh Pentz (Pentz, 2015) various fabrics were discussed in terms of their waterproofing, breathability and durability. The material that provided the preferred aesthetics and flexibility for manufacturing consists of a 85% PA (Polyamide) / 15% EA (Elastane) which has a 100% PU (Polyurethane) membrane and PES (Polyester) inner lining. To validate that material performed as expected, a 120mm*120mm sample was exposed to a running water for 15 minutes. No water throughput occurred, with the outer layer drying quickly (Figure 4.54). This proposal provides wind/rain protection as well as ventilation without requiring much thinking on the part of the user. To validate the amount of ventilation occurring, further testing will need to be conducted.

As previously proposed, the fabric screen can be integrated with the low radiative heat padding (Figure 4.53). The padding itself has been extended upwards to cover a greater area of the exposed fibreglass body. It consists of two vacuum formed ABS panels covered in highly durable schoeller®-dynatec material connected via a hem stitched collapsible backing (Figure 4.53). This allows the padding to be easily removed; allowing for storage in drier and warmer seasons. The left and right panes are held in place by fibreglass or carbon composite T-rails screwed to the fibreglass body (Figure 4.53). Alternatively these rails can be manufactured from blow molded plastic, however this will depend on production volumes. The T-rails act as a door 'rests' as well as providing the space needed for the latch attachment pin.

Figure 4.53: Ventilation and Low heat radiating padding (Cassim, 2015)

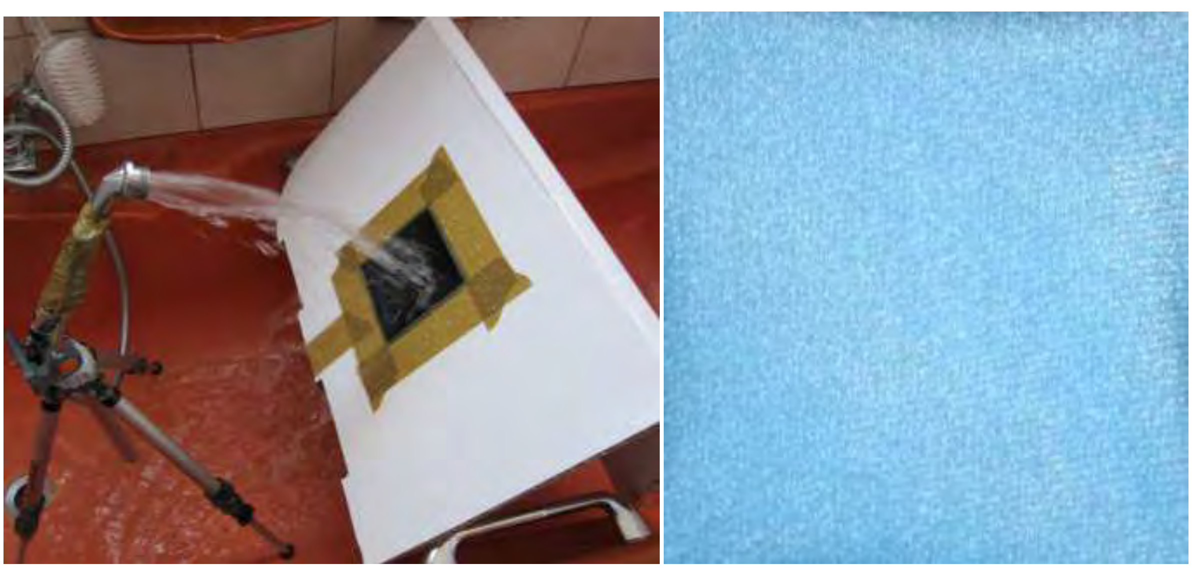


Figure 4.54: Material validation (Cassim, 2015)

LIGHTING VALIDATION

Regarding the exterior lighting, both traditional LED's (light emitting diodes) as well as various SMD (surface mounted) LED's were tested. To provide the ADA required 0.5m area of illumination outside the vehicle, LED's rated at least 1000 lumens were needed to provide the requisite lighting. Tests were conducted with 5, 8, and 24 SMD LED's at height of approximately 212 mm (The distance from the bottom of the vehicle to the ground) (Figure 4.55). Testing was conducted in a darkened room with low ambient light to simulate early morning/late afternoon use.

Figure 4.55: Lighting validation: Top -24, 1000 lumen SMD LED's; Middle – 8, 1000 lumen SMD LED's; Bottom 5, -1000 Lumen SMD LED's (Author, 2015)

Of the 1000 lumen LED's, the first configuration to be tested were 8 LED's pointed downwards at 25 degrees from the horizontal. This gave the desired ADA mandated 0,5m area Illumination (measured in a straight line from the LED in the direction of entry). They were however still visible from a standing position 2 meters away, creating unnecessary glare that hampered vision. When tilted to 65 degrees from the horizontal no glare was apparent; with the illumination still sufficient.

As the 8 LED configuration already proved appropriate, the results from the 24 LED configuration will not be discussed. A 5 LED configuration (as in the initial concept sketches) was tested by covering up 3 of the 8 LED's (Figure 4.56). These also provided sufficient illumination to comply with ADA standards. It must be noted while these LED's had no lenses to direct or diffuse light, they did poses cone shaped reflectors.

Figure 4.56: 5, 1000Lumen SMD LED’s next to 60cm ruler (Left Photo taken from 50cm mark) (Author, 2015)

AESTHETIC CONSIDERATIONS

Regarding the aesthetics of proposed adaptations, various concepts were proposed to a focus group whom were asked to rate them on various criteria. In regards the soft handrails, various pattern and colour combination were put to the group whom were asked to rate them in terms of perceived detect-ability as well as appeal. Three out of four chose example D for both, while one chose E for visibility and A for trendiness.

Figure 4.57: Hand rail design proposals (Cassim, 2015)

To provide consistency (as this is a tenant of UD Design) I propose applying the same colour scheme to the exterior door handles, allowing the user to quickly identify which areas of the vehicle are touch points. Highly reflective yellow door handles should be set against a matt black backing to help create a highly defined outline which should make locating the handle easier in low visibility conditions.

The focus group was also presented with the frame designs mentioned in the ‘Door sealing and frame design’ section. Based on their feedback and that of the original co-design group it was decided to select the frame that splits the side pane into three sections; with the middle section darkened. It was unanimous that this design followed the lines of the vehicle the closest, while at the same time appearing the trendiest. To retain the smooth outer look, it was decided to attach the outer pane to the frame via liquid polyurethane bonding instead of mechanical fasteners.


INTEGRATION OF DESIGN ADAPTATIONS (Cassim, 2015)

CHAPTER 5

5.0. CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

This thesis highlights that the design of ingress and egress systems for MMV’s is an area deserving the attention of Industrial Designers and Ergonomists. It raises the question whether virtual posture analysis can be utilized by Industrial Designers to evaluate the ergonomics of passengers' ingress and egress movements in MMV's.

It succeeds in answering this question with the development of a virtual model to perform ingress and egress motion. Additionally, it succeeds in performing an ergonomic evaluation of the Mellowcabs design and validates the practicality and plausibility of a door design concept.

From the literature and theory stated, the designers were able to supply answers to the statement of the problem, the purpose of the study, and questions by the choice of instruments and methodology of the study. The major tenants of the theory i.e. human centered design, universal design, product semantics, and affordances are highlighted.

A universal design approach to the usability concern has intrinsic benefits; as all of its principles centre on providing the most efficient and understandable man/machine interaction for the largest group of people. This is a vital; as it is the mismatch between what the vehicle offers and what the user desires that causes the usability problem in the first place.

Combining Universal Design with Human Centred Design methods has led to a solution that is hopefully as trendy as it is usable. This is an important statement, as a large part of universal design is about not stigmatising those with disabilities by excluding those without. The design proposes (within the limitations of the base vehicle) to be as inclusive as possible.

For example the quality of components was found to be the big deciding factor, since this experience of just one defect in a vehicle can actually affect one's judgement towards all other aspects of the vehicle. Measurement and evaluation has given a better understanding of how packaging of vehicle interiors contribute to automotive ergonomics. In the context of this thesis product semantics allowed for a body into which data from anthropometric, ergonomics, product and user trends could be integrated to develop a final door design concept.

By utilizing parametric CAD software it was possible to predict the outcome of various human activities, such as motion related issues with ingress and egress without having to physically create prototypes or apparatuses. By investigating the attributes of a manikin in a given virtual environment (3D space), designers and engineers created a better understanding of the constraints and needs of the occupant. In the context of this thesis the use of digital mock-ups, together with digital human models (DHM) had proven to reduce the total engineering development cost of the door design by assessing the ergonomics through virtual simulation. In addition, it enables designers and engineers to assess a vehicle's ingress and egress performance early in the design process, which leads to better vehicle packaging.

In future, utilising this approach to design a vehicle from scratch could create a truly inclusive vehicle. While the proposed adaptations should have a marked positive effect on user uptake, the base vehicle design limits the ability to fully integrate the vehicle in the larger transport infrastructure. It is thus proposed that further research be done into Micromobility commuter vehicles through the lens of universal design; catering for both able and disabled persons.

DOOR DESIGN

The door design Concept MC-B features a door that pivots vertically to the front of the vehicle (scissor car door). This saves space when opened. Therefore, Concept MC-B was established as the final door design for further development.

The analysis performed on the basis of known usability theory proved crucial in establishing the practicality and plausibility of the final door design and the desired door mechanism to be developed for the Second Edition Mellowcabs Electric Vehicle.

Besides establishing the viability of door design Concept MC-B it also established the suitability of the design in terms of usability as the studies proved the door operation, in any type of situation, will not hamper the ingress or egress movements of humans or cause any other type of human discomfort.

INGRESS AND EGRESS SIMULATION

It was discovered that the biggest difference between ingress and egress, was that ingress and egress motion interacts with geometries. While a person could walk without any geometry, ingress and egress motion has to have an object to get in and out of. During the ingress or egress motion, a person cannot strike any object. Therefore each frame and individual component of the object is an obstacle to avoid, so collision avoidance had to be considered for movement inputs.

It was essential that the correct anthropometric data was captured by the software when incorporating the human factors in a virtual environment. The important aspects such as ingress and egress could therefore be assessed to a good degree of accuracy by utilizing the parametric CAD software. In the context of this thesis factors considered were passenger view (inside and outside), door entry and exit, rear passenger clearance, and spaciousness.

While substantial benefits can be gained from implementing the tools presented in this thesis, a few limitations must be kept in mind such as the wide variance in ingress and egress strategies among passengers. In order to simplify the problem, tasks assumptions were described in Chapter 4. Since the numbers of tasks are limited to four, it may limit the passenger's strategy.

The virtual simulation concluded that the new Second Edition Mellowcab Electric Vehicle meets the required occupant packaging standards, as the manikin successfully accomplished all the ingress and egress tasks, indicating that a person will be able to successfully enter and exit the vehicle. Additionally, the manikin was able to accomplish all the ingress and egress tasks with the proposed concept MC-B door at its maximum opened position. No clashes were detected that could hinder the manikins ingress and egress movement whilst it passes the bottom-door edge, and the side-back window.

POSTURE ANALYSIS

Considering the findings of the posture analysis it can also be concluded that some changes in interior dimensions, especially in seating positions and sitting angles, are required in this vehicle. Taking mental workload results into account it can be concluded that the interior design of the Mellowcabs vehicle had no influence on the passengers' mental workload. Additionally, the angles of trunk and hand-arm should be increased and angles related to the knee and foot should be decreased. From the aspect of comfort or discomfort, the Mellowcabs vehicle showed a neutral state among passengers. Optimizing seating angles, decreasing vibration, correcting stiffness or seating pan are suggested for customization of the ergonomic aspect of this vehicle.

5.2. RECOMMENDATIONS

Concerns were raised with positioning of the driver seat, as it interferes and can cause discomfort to the passenger manikin entering and exiting the vehicle. The driver seat could be adjusted forward away from the passenger seat to allow for an easier rotating action, and to allow more space in the passenger cabin.

Additionally, the driver seat back rest is leaning excessively towards the passenger seats. Adjusting this degree of angle will not only benefit manoeuvrability in the passenger cabin space, but also secure better seating ergonomics for the driver. Finally, the driver seat head rest was found to be used as a support structure and determined as a hand input, yet the results indicate that it is too high for a comfortable reach, and therefore the addition of hand rails are proposed.

Although the higher door sill needed more strain from the manikin to exert, such as to lift his feet over the sill, it did not affect the ease of lifting his legs in or out of the vehicle. However the door-sill should be well rounded and have a smooth surface with no sharp edges to permit people's feet to easily glide over.

While at this point the vehicle door closing and opening once the passengers are inside is handled by the driver, it is recommended that an interior door handle be adopted. This is to provide redundancy in case of an emergency or failure of the driver door lever.

The current door mechanism does not have a lock holding it open in the forward position. It was borne out in the user tests that commuters might utilise the lower part of the door to aid entry once it is in the forward position. A lock will help stabilise the door.

While the exterior lighting is proposed to activate once the door is open, ambient lighting control should also be added to cater for various levels of environmental brightness.

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APPENDIX A

USABILITY TEST

We'll be conducting some product testing today for the Mellowcabs MMV.
(Explain – then ask Neil du Preez to explain his bit)

1. Four types of short tests will be conducted. Three individually and one in groups of two.
2. Firstly we'll be conducting a wet weather test. Here you'll simply be required to approach the vehicle as directed and enter the vehicle. The participant will require to sit in the vehicle for a minimum of 4 minutes before exiting the vehicle.
3. Participants may get wet during wet weather testing.
4. The process will be recorded via video.
5. After the completion of the above test the participant will be required to fill in a questionnaire relating to that specific test.
6. Reduced lighting test will require you to wear darkened goggles and perform an ingress and egress test. A few short questions will be asked relating to this test.
7. For the dry test, feel free to act out how you would go about this whole process if you were taking an actual Mellowcab in CT, let's say from work the station…
8. Do not be afraid to verbalise what they are doing.
9. As this is not a fully completed model there are things that will need to be imagined.

   Explain. At this point we'll have the, 'where to put the tablet interface screen'. (Also should the mapping be constantly available on screen?) Ask user to physically simulate its use. And Comment on any issues. i.e. can you reach the screen while buckled in?
10. The final test will be a double up test with two passengers. Feel free to comment on comfort levels or anything else you observe.
11. A mini focus group/workshop session will be conducted after the completion of testing.

APPENDIX B

PARTICIPANT A: DRY WEATHER TEST

Female, 23, Industrial Design Student

Entry: Dry
Time for entry – From the right foot initial lift to seated position – 9 seconds

1. Uses Rear door sill and Drivers headrest for leverage to enter vehicle.
2. Hooks hand around driver's headrest to allow pivoting into a seated position.
3. No confusion as to foot placement as she is looking down.
4. Jacket gets caught on protrusion from seat backrest. (This would indicate very tight clearance between drivers arm and passenger while entering the vehicle.)
5. Participant positions themselves initially in the centre and then shuffles over to the right hand side of the vehicle.
6. The right-hand side sill is used as an armrest. Attention paid to the space/area behind the driver is notable.

Exit: Dry
Time to exit – From initial forward lean to both feat outsidethe vehicle – 4 seconds

Talk as you go:
1. Roof feels claustrophobic, suggests roofline start further back. (Issue fixed on never version)
2. Feel likes she is sitting on an angle – possibly due to the lack of any additional foot nook.
3. The seat remind her of the army.
4. Very rigid seats.
5. The visibility of the mechanical bits was intimidating.
6. She would like storage space, but is prone to forgetting her stuff.

APPENDIX C

PARTICIPANT A: WET WEATHER TEST

Female, 23, Industrial Design Student

Entry: Wet

Time for entry – From the right foot initial lift to seated position – 4 seconds

As can be seen the familiarity of the vehicle reduces (even in though the second timed entry was done in wet conditions)

7. Uses Rear door sill and Drivers headrest for leverage to enter vehicle.
8. Holds top of drivers headrest to allow pivoting into a seated position.
9. No confusion as to foot placement as she is looking down.
10. In seated position participant sits very upright (possibly to avert weather condition) Head clearance between canopy and head becomes an issue.
11. Participant positions themselves in the centre and then stays there for the entire test period.
12. The right-hand side sill is now not being used as an armrest.
13. Passenger Visibly tries to isolate herself from the weather
14. She appears much less relaxed than in dry test.
15. Reacts surprised and aversive towards a sudden spray of water to simulate mild wind conditions, uses an additional jacket to cover her legs.
16. At this point water has started to pool on the floor.
17. Participants starts to notice water dripping from the roof inside the cabin from either side.
18. Water also runs down and bounces of sills into the cabin.
19. Participant lifts herself from seat as it has now started to become saturated on the outsides.
20. At this point 3 minutes (average time for a journey – do research on this) has past.
21. Grabs the front of the driver's headrest (where the head would be) to aid exit.

Exit: Wet

Time to exit – From initial forward lean to both feat outside the vehicle – 7 seconds

As can be seen exist time increases significantly, even with vehicle familiarity.

APPENDIX D

LOW VISIBILITY TEST – PARTICIPANT A

Entry Timing

Timing from the lifting of the entry foot off the ground to seated position. Approx. 20 seconds.

1. Initial reach for side sill fails.
2. Tentative positioning of entry(left) foot
3. Utilises first the left side sill and then the right side sill support before pivoting into place.
4. Immediately tries to adopt central seating position.
5. Tentatively adjusts seating position to attain a comfortable spot.

Exit timing

Timing from start of first movement to both feet on the ground Approx. 4.5 sec.

1. Utilises side sill and drivers headrest as leverage and stability upon vehicle exit.

APPENDIX E

PARTICIPANT B: DRY WEATHER TEST

Male, 23, Engineering Student

Entry: Dry

Time for entry – From the right foot initial lift to seated position – 4 seconds

22. Initially goes for door sill and roof rail to aid entry. Does not find appropriate roof rail aid.
23. Uses Rear door sill and Drivers headrest for leverage to enter vehicle.
24. Hooks hand around driver's headrest to allow pivoting into a seated position.
25. No confusion as to foot placement as he is looking down.
26. Immediately chooses to sit in a central position.
27. Moves to his left, finds the sill a comfortable armrest, good, height, no taper.

Exit: Dry

Time to exit – From initial forward lean to both feat outside the vehicle – approx. 2.5 seconds

Utilises left sill and seat as stabiliser/push-off to aid vehicle exit.

Talk as you go:

1. Does not lean back, sits rather upright. Would prefer an adjustable seat.

APPENDIX F

PARTICIPANT B: WET WEATHER TEST

Male, 23, Engineering Student

Entry: Wet

Time for entry – From the right foot initial lift to seated position – 4 seconds

Entry and exit time are the same – Participant has however had previous experience with entry and exit of this vehicle.

28. Uses Rear door sill and Drivers headrest for leverage to enter vehicle.
29. Wraps head around drivers headrest to allow pivoting into a seated position.
30. No confusion as to foot placement as she is looking down.
31. Participant positions themselvesclose to the centre.
32. Participant immediately notices water seeping inside and checks if his arm to see if he got wet.
33. Readjust position round the centre area of the seat to avoid getting wet.
34. He appears much less relaxed than in dry test.
35. The vehicle backrest is now also visibly wet.
36. At this point water has started to pool on the floor.
37. Water also runs down and bounces of sills into the cabin.
38. Grabs the front of the driver'sheadrest and left sill (where the head would be) to aid exit.

Exit: Wet

Time to exit – From initial forward lean to both feat outsidethe vehicle – 4.5 seconds

As can be seen exist time increases significantly, even with vehicle familiarity.

Talk as you go:

1. Confirms water ingress increases during vehicle shaking (to simulate bumpy roads)

APPENDIX G

LOW VISIBILITY TEST – PARTICIPANT B

Entry Timing

Timing from the lifting of the entry foot off the ground to seated position. Approx. 5 seconds.

6. Utilises the left side sill and drivers headrest for leverage and stability upon entry.
7. Immediately adopts a central seating position.

Exit timing

Timing from start of first movement to both feet on the ground Approx. 5.5 sec.

2. Utilises side sill and drivers headrest as leverage and stability upon vehicle exit.
3. Hesitation and tentative foot movement evident.

APPENDIX H

PARTICIPANT C: WET WEATHER TEST

Male, 38, Entrepreneur, Tall

Entry: Wet

Time for entry – From the right foot initial lift to seated position – 3 seconds

Participant has had previous experience with entry and exit of this vehicle.

39. Uses seat and driver's seat back for leverage to enter vehicle.(Would interfere if driver were present)
40. No confusion as to foot placement as she is looking down.
41. Participant positions themselves close to the centre.
42. Repositions himself with the aid of the left hand sill.
43. Participant does not appear relaxed.
44. Mild wind/shake simulation shows wetting of participant's jacket. Water is seen streaming in down the sills.
45. The vehicle backrest is visibly wet.
46. Grabs the front of the driver's headrest and left sill (where the head would be) to aid exit.
47. Audible squeaking from shoes is heard as participant exits.

Exit: Wet

Time to exit – From initial forward lean to both feat outside the vehicle – 3 seconds

No dry entry timing was available.

Talk as you go:

Initial didn't feel water ingress was too bad. However changed his mind during shake/wind simulation.

APPENDIX I

PARTICIPANT D: WET WEATHER TEST

Male, 26, Industrial Design MTech Student, Medium build/lanky

Entry: Wet

Time for entry – From the right foot initial lift to seated position –approx. 5.5 seconds

Entry and exit time are the same – Participant has however had previous experience with entry and exit of this vehicle.

48. Uses Rear door sill and Drivers headrest for leverage to enter vehicle.
49. Wraps head around drivers headrest to allow pivoting into a seated position.
50. Participant positions themselvesclose to the centre.
51. Readjust position round the centre area of the seat to avoid getting wet during wind/shake test.
52. Does not appear at all relaxed
53. Readjusts again to the front edge of the seat to avoid the water that has now soaked in.
54. The vehicle backrest is now soaked with no clear/dry patches on the left-hand side (mild breeze/wind simulation side)
55. At this point water has started to pool on the floor.
56. Participant has not removed the cap of his rain jacket.
57. Arms get wet during breeze/shake test as water bounces off the sill onto his sleeve.
58. Grabs the front of the driver'sheadrest and left sill (where the head would be) to aid exit.

Exit: Wet

Time to exit – From initial forward lean to both feat outsidethe vehicle – 5 seconds

Lip of side sill interferes slightly with feet while exiting vehicle.

Talk as you go:

2. Notices and remarks that vehicle is soaking wet on the inside.
3. Remarks that his thighs were getting wet.
4. Remarks that feet were getting soaked.

APPENDIX J

LOW VISIBILITY TEST – PARTICIPANT D

Entry Timing

Timing from the lifting of the entry foot off the ground to seated position. Approx. 7 seconds.

8. Utilises left side sill and drivers headrest before pivoting into place.
9. Slight interference of foot by left hand sill.
10. Immediately tries to adopt central seating position.
11. Tentatively adjusts seating position to attain a comfortable spot to the left. Finds head bumps against crossbar during this activity.
12. Utilises left hand sill as an armrest.

Exit timing

Timing from start of first movement to both feet on the ground Approx. 3.5 sec.

4. Utilises side sill and drivers headrest as leverage and stability upon vehicle exit.

APPENDIX K

PARTICIPANT E: WET WEATHER TEST

Male, 31, Industrial Design Student, Short, Large

Entry: Wet

Time for entry – From the right foot initial lift to seated position – 4,5seconds

Entry and exit time are the same – Participant has however had previous experience with entry and exit of this vehicle.

59. Uses Rear door sill and Drivers headrest for leverage to enter vehicle.
60. Wraps head around drivers headrest to allow pivoting into a seated position.
61. No confusion as to foot placement as he is looking down.
62. Participant positions themselves close to the centre.
63. Participant comments on how wet he's pants are getting.
64. Breeze/shake test curves water straight from the roof onto participant's jacket.
65. Grabs the front of the driver's headrest and left sill (where the head would be) to aid exit.

Exit: Wet

Time to exit – From initial forward lean to both feat outside the vehicle – 4.5 seconds

Talk as you go:

5. Remarks that it is possibly not the best vehicle for business suites or light coloured clothing.
6. Remarks that the light shining through the back gives it a nice and open feeling.

APPENDIX L

LOW VISIBILITY TEST – PARTICIPANT E

Entry Timing

Timing from the lifting of the entry foot off the ground to seated position. Approx. 5.5 seconds.

13. Utilises the left side sill and drivers headrest for leverage and stability upon entry.
14. Immediately adopts a central seating position.
15. Participant notices lack of head clearance when sitting back against the seatback.

Exit timing

Timing from start of first movement to both feet on the ground Approx. 4.5 sec.

5. Utilises side sill and drivers headrest as leverage and stability upon vehicle exit.
6. Unsure of vehicle head clearance upon exit.
7. Tentatively looks t foot positioning although with no error as such.

APPENDIX M

Wet weather tests questionnaire

1. From the introduction earlier, was getting into the vehicle easier or more difficult than expected? Please explain.

It was fairy easy $ quite simple. There warnt as much grip to hold onto when I was getting in. The front seat, snatched my jacket.

2. Was egress/exit any easier or harder than expected? Please explain.

It was much easier than getting in. Had to be cautious with my head, not to bump it.

3. Regardless of the ease with which you accomplished the above tasks, were there any worries such as slipping, falling, frustration, etc.

No frustration. - It was actually quite enjoyable very comfortable seats, regarding the erconomics, however the material a bit raw $ too regid.

4. What were you impressions of the vehicle in these conditions?

The shape of the design reminded me of a very good example of air dynamics $ good air flow (speed). Very good idea of transportation.

5. What were your expectations beforehand?

None: I didnt know what to expect!

PLEASE TURN OVER/…………

6. During the winter season, would you feel comfortable traveling for up to 3km in such a vehicle? Please explain why.

Yes, I would feel comfortable. 1st: It's much better than walking in such winter conditions & It's surely much faster.

7. Does this vehicle provide enough weather protection for Cape Town winters?

Perhaps not with the wind (CT: Jan-April) But with rainy conditions, yes! ü

8. Please add any additional comment you may have below.

Perhaps a non-slip floor or grid to be added. Section of the floor in the middle uncomf.

Thank.

Wet weather tests questionnaire

1. From the introduction earlier, was getting into the vehicle easier or more difficult than expected? Please explain. Vehicle ~~??~~ ingress was relatively easy, although I had to consciously be aware of step height into vehicle, as the shape is rounded.

2. Was egress/exit any easier or harder than expected? Please explain.
~~e~~ Egress was ~~easy~~ easier than expected, as I used the driver seat ~~as a~~ to aid with pulling myself out

3. Regardless of the ease with which you accomplished the above tasks, were there any worries such as slipping, falling, frustration, etc.
Yes, due to the round edges one is generally more likely to slip (personal experiences)

4. What were you impressions of the vehicle in these conditions?
~~Be~~ Very little room was ~~Fefe~~ left (Dry areas), due to ~~the~~ there being no cover on the sides, giving one a feeling of restriction & discomfort.

5. What were your expectations beforehand?
At first I expected ingress & egress to be more difficult. I expected ~~a lit~~ to be slightly more wetter.((However weather conditions can-not be controlled). I did expect restriction due to water entering vehicle, but did not expect the seats to be as wet as they were.

PLEASE TURN OVER/............

6. During the winter season, would you feel comfortable traveling for up to 3km in such a vehicle? Please explain why.

Yes, I don't like walking in the rain. ~~Especially when you~~ ~~are~~ ~~Note~~ I don't particularly enjoy having damp clothing

7. Does this vehicle provide enough weather protection for Cape Town winters?

~~Unlikely~~. No, weather conditions can be very harsh in cape town & ~~up~~ unpredictable as is proven many times with road accidents

8. Please add any additional comment you may have below.

- flat surface for ~~a~~ comfortable foot space, will also allow feet to move freely.
- Seats are not adjustable (seats ~~are~~ relatively higher than most cars)
- A door would be preferable during winter times
- no alignment between ~~top~~, rear, top inside edge and rear, bottom inside edge

~~- during~~

Wet weather tests questionnaire

1. From the introduction earlier, was getting into the vehicle easier or more difficult than expected? Please explain.

EASIER ... THE OPENING HAS ENOUGH ROOM TO PASS THROUGH. HOWEVER DRIVER SEAT SEEMS TOO CLOSE TO THE ENTRY

2. Was egress/exit any easier or harder than expected? Please explain.

EASIER, THOUGHT WOULD BE TOO HIGH FROM FLOOR. YET WHILST ENTERING & EXITING THE VEHICLE WAS NOT STURDY BUT SHIFTED FROM SIDE TO SIDE.

3. Regardless of the ease with which you accomplished the above tasks, were there any worries such as slipping, falling, frustration, etc.

YES, DUE TO THE BUILD UP OF WATER DAMS WITHIN THE CABIN.

4. What were you impressions of the vehicle in these conditions?

TOTALLY UNIMPRESSED. SIDES ARE SOAKING WET, THE SEAT WAS COMPLETELY WET. WATER KEPT SEAPING IN.

5. What were your expectations beforehand?

DIDNT HAVE ANY...

PLEASE TURN OVER/…………

6. During the winter season, would you feel comfortable traveling for up to 3km in such a vehicle? Please explain why.

NO. GET WET.

7. Does this vehicle provide enough weather protection for Cape Town winters?

DEFINETY NOT. SORRY TO SAY..

8. Please add any additional comment you may have below.

- CHECK DRIVER SEAT DISTANCE OR ADJUSTABILITY
- CHECK FOR EFFICIENT ~~STO~~ STORAGE SPACE.
- THINK OF WATER SEAPING IN ~~AT~~ BACK FROM SIDE
  - ↳ WINDOW?
  - ↳ COVER ?
- → THINK OF SEATING MATERIAL ...

Wet weather tests questionnaire

1. From the introduction earlier, was getting into the vehicle easier or more difficult than expected? Please explain.

Entry was fine. I didn't slip - which is what I expected. Also the entry wasn't that high.

2. Was egress/exit any easier or harder than expected? Please explain.

Very Easy

3. Regardless of the ease with which you accomplished the above tasks, were there any worries such as slipping, falling, frustration, etc.

Just the water running down my bum. Feelings calming in the back.

4. What were you impressions of the vehicle in these conditions?

A bit exposed.

5. What were your expectations beforehand?

To get alot more wet. To struggle getting in. - Too high. -> look big & intimidating from the outside and feels comfortable on the inside.

PLEASE TURN OVER/............

6. During the winter season, would you feel comfortable traveling for up to 3km in such a vehicle? Please explain why.

If it had doors. - But ones that don't spoil the view out. Currently too much water gets in.

7. Does this vehicle provide enough weather protection for Cape Town winters?

No.

8. Please add any additional comment you may have below.

Wet weather tests questionnaire

1. From the introduction earlier, was getting into the vehicle easier or more difficult than expected? Please explain.

Easier.

2. Was egress/exit any easier or harder than expected? Please explain.

exit was harder than expected. There was a puddle on the floor.

3. Regardless of the ease with which you accomplished the above tasks, were there any worries such as slipping, falling, frustration, etc.

Yes, slipping was a risk, as surfaces were wet + slippery.

4. What were you impressions of the vehicle in these conditions?

Not really comfortable.

5. What were your expectations beforehand?

It looks like a great vehicle for summer use.

PLEASE TURN OVER/…………

6. During the winter season, would you feel comfortable traveling for up to 3km in such a vehicle? Please explain why.

Not in the Cape. Too wet + cold.

7. Does this vehicle provide enough weather protection for Cape Town winters?

No, the vehicle requires isolation from the elements.

8. Please add any additional comment you may have below.

APPENDIX N

Low visibility test

1. How did your impression of the vehicle change in low visibility conditions?

THE DARKENED GLASSES MADE IT MORE DIFFICULTY TO JUDGE THE STEP HEIGH. WAS ALSO DIFFICULT TO JUDGE THE SPACE INSIDE THE CAB.

2. Was the 'kerbing' sufficiently visible when trying to exit the vehicle?

YES.

3. Please add any additional comment you may have below.

- HEAD SPACE
- INSIDE LIGHTING
- HEAD REST

Low visibility test

1. How did your impression of the vehicle change in low visibility conditions?

More difficult. Unsure whether my head would bump. No worries about feet. Do feel around a little.

2. Was the 'kerbing' sufficiently visible when trying to exit the vehicle?

Yes.

3. Please add any additional comment you may have below.

You lose the sense of openess you had. when. ~~you~~. in daylight.

Low visibility test

1. How did your impression of the vehicle change in low visibility conditions?

Not much from my previous experience .

2. Was the 'kerbing' sufficiently visible when trying to exit the vehicle?

Yes, as there was enough grip areas for me to grapple.

3. Please add any additional comment you may have below.

any built-in lights for future reference?

Low visibility test

1. How did your impression of the vehicle change in low visibility conditions?

I ~~You~~ tended to be more cautious, which slowed down ingress & egress.
I am not sure of hand placement on supports

2. Was the 'kerbing' sufficiently visible when trying to exit the vehicle?

Yes, the vehicle colour does aid with visibility as it allows one to have better perception of depth ~~at~~ ~~low~~ with litte lighting

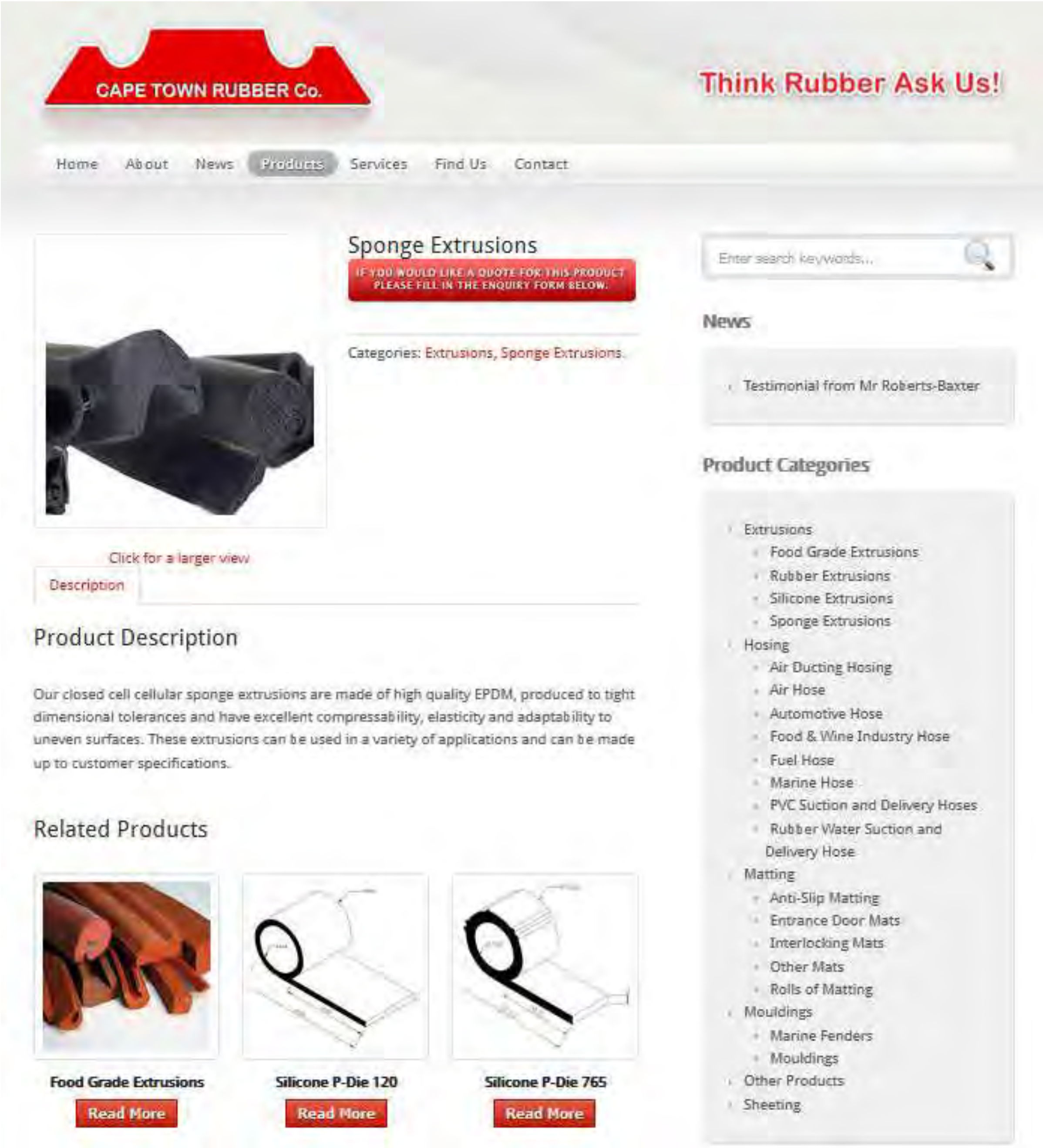
3. Please add any additional comment you may have below.

Hand placement during ingress & egress might disturb the driver.
~~Seat~~

APPENDIX O

http://www.schoeller-textiles.com/en/fabric-groups/protection/schoeller-dynatec.html

APPENDIX P



http://www.ctrubber.co.za/shop/sponge-extrusions/

APPENDIX Q

Properties (This table summarizes the major physical properties typical values at 23 °C/50 % R.H)

Properties	PLEXIGLAS® Resist 45 Clear 0RA45	PLEXIGLAS® Resist 65 Clear 0RA65	PLEXIGLAS® Resist 75 Clear 0RA75	PLEXIGLAS® Resist 100 Clear 0RA00	Unit	Test Standard
Density	1,19	1,19	1,19	1,19	g/cm^3	ISO 1183
Impact strength (Charpy)	45	65	75	no break	kJ/m^2	ISO 179/1 fu
Notched impact strength (Charpy)	3,5	6,5	7,5	8,0	kJ/m^2	ISO 179/1 eA
Tensile strength	60	50	45	40	MPa	ISO 527-2/1B/5
Nominal elongation at break	10	15	20	25	%	ISO 527-2/1B/50
Elastic modulus (short-term value)	2700	2200	2000	1800	MPa	ISO 527-2/1B/1
Flexural strength	95	85	77	69	MPa	ISO 178
Cold-curving radius, min.	270 x thickn.	210 x thickn.	180 x thickn.	150 x thickn.	–	–
Coefficient of linear thermal expansion (0 to 50°C)	$7 \cdot 10^{-5}$ (= 0,07)	$8 \cdot 10^{-5}$ (= 0,08)	$9 \cdot 10^{-5}$ (= 0,09)	$11 \cdot 10^{-5}$ (= 0,11)	1/K (mm/m°C)	DIN 53752-A
Permanent service temperature, max.	70	70	70	65	°C	–
Reverse forming temperature	> 80	> 80	> 75	> 70	°C	–
Vicat softening temperature	101	100	100	97	°C	ISO 306, Method B50
Transmittance (380–780 nm)	91	91	91	91	%	DIN 5036, Part 3
UV transmission	none	none	none	none	–	–
Surface resistivity	$> 10^{14}$	$> 10^{14}$	$> 10^{14}$	$> 10^{14}$	Ohm	DIN VDE 0303, Part 3
Fire rating	B2	B2	B2	B2	–	DIN 4102
Water absorption (24 h, 23°C) from dry state; specimen 60 x 60 x 2 mm^3	41	45	46	49	mg	ISO 62, Method 1

http://www.plexiglas-shop.com/pdfs/232-1-PLEXIGLAS-Resist-45-%2065-%2075-%20100-en.pdf

Product and Application

Extruded PLEXIGLAS® Resist is a highly weather-resistant sheet material from **impact-modified** acrylic (polymethyl methacrylate, PMMA). The grades Resist 45, -65, -75, -100 show increasing impact strength in that order. The sheets therefore offer **greater break resistance** than standard acrylic during

- transport and handling,
- the entire fabrication process,
- installation and
- subsequent use.

PLEXIGLAS® Resist combines the positive properties of PMMA with the toughness of other plastics such as polycarbonate (PC). The opposite graph shows the impact resistance of Resist sheets as compared with PC and the basic grade PLEXIGLAS® XT 20070.

Very often, extreme break resistance is uneconomical. In this case, the individual, custom-tailored solutions offered by PLEXIGLAS® Resist are particularly advantageous.

PLEXIGLAS® Resist is highly weather resistant and durable. Unlike other plastics (e.g. PC, PET, PETG) it requires no additional UV protection. PLEXIGLAS® Resist is therefore a highly versatile and absolutely reliable material for

- structural glazing outdoors, e.g. barrel vaults for busstops, bicycle stands, walkways,
- protective glazing such as general access protection, housings for machines, equipment and workplaces,
- vehicle glazing, e.g. windshields for motorcycles and scooters, interior glazing in buses and trains,
- glazing of shop fittings and counters,
- signage, e.g. illuminated signs, indicator panels, advertising pillars,
- P.O.P. displays and sales stands, glazing of vending machines, drawing equipment etc.

In the field of vehicle glazing, PLEXIGLAS® Resist 75 is suitable for use in classes E to F according to the German regulation ABG No. 2326 (e.g. trailers, caravans, building site vehicles, forklift trucks, motorcycle windshields etc.). Moreover, it is approved to DOT-112, AS-6, M-34 to M-84.

All clear-transparent Resist sheets are approved for food-contact applications.

Chemical Resistance

The chemical resistance roughly corresponds to that of PLEXIGLAS® XT 20070. We will be pleased to answer specific inquiries about compatibility with given substances.

Machining

Owing to its increased toughness, PLEXIGLAS® Resist lends itself perfectly to sawing, drilling, milling, grinding and polishing under conditions corresponding to the material. Twist drills must have specially ground bits for acrylic. Only slight pressure should be exerted during polishing. For more precise recommendations, please consult our Guidelines for Workshop Practice.

The appropriate accident prevention regulations and statements of tool manufacturers must be observed during machining. PLEXIGLAS® Resist can be laser-cut. The gloss of the lasered edge changes at increasing impact strength. Clear edges can be obtained by wiping them with petroleum ether.

Bonding

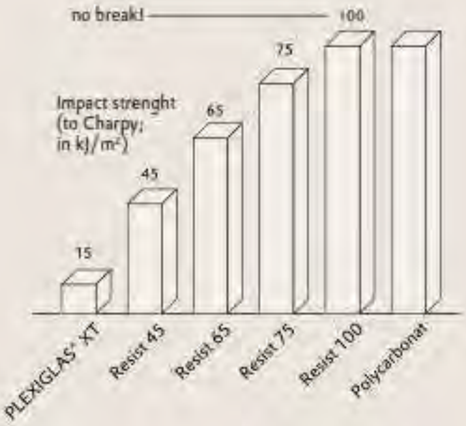
PLEXIGLAS® Resist is as easy to bond as the basic grades of PLEXIGLAS® XT, e.g. using the solvent-type adhesives ACRIFIX® 1S 0116 and 1S 0117 as well as the gap-filling polymerization adhesives ACRIFIX® 1R 0192 and 2R 0190. With the latter, it should be borne in mind that the joints show lower impact strength than the bonded parts made of PLEXIGLAS® Resist. The bond strength diminishes at increasing impact strength.

Forming

The forming conditions are the same as for PLEXIGLAS® XT basic grades. The thermoforming temperature should be between 140 °C and 160 °C, the range in which the material is thermoelastic. There is no need for predrying provided the sheets are stored correctly, covered with their protective PE masking.

The material turns white during heating but this color disappears again as the material cools down.

PLEXIGLAS® Resist can also be installed cold-curved, provided the minimum cold-curving radius is observed (see table).



http://www.plexiglas-shop.com/pdfs/232-1-PLEXIGLAS-Resist-45-%2065-%2075-%20100-en.pdf

APPENDIX R

2.2 General Glazing

2.2.1 Compatible products

When installing Perspex® glazing panels it is essential to ensure that all ancillary products and materials used in contact with the sheet are fully compatible with acrylic. Failure to observe this may result in permanent damage to the Perspex® glazing. For example, rubber sealing strips and profiles should be made from butyl rubber or polysulphide rubber. Certain EPDM rubbers can be used as alternatives, as can compatible silicone sealants, **but in all cases it is important to seek the advice of the product supplier before use. Plasticised PVC sealing strips should not be used under any circumstances as these are known to cause stress crazing of acrylic sheets.**

2.2.2 Recommended thickness of Perspex® for Windows

The required thickness is dictated by two considerations. The first is the desired impact strength and the second is the wind loading which an external window must sustain. In most countries statutory requirements or codes of practice exist which specify wind loads for building structures and these must be followed. For example, in the United Kingdom, BS CP3 Chapter V Part 2 is the Code of Practice to be followed when designing windows or glazed structures.

Figures 15 and 16 give the recommended thicknesses of Perspex® for various wind loads.

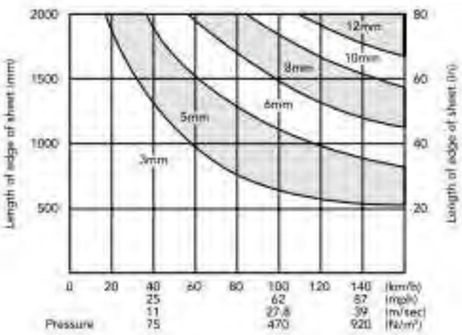


Figure 15 The recommended thicknesses of Perspex® for various wind loads when designing for square windows, with all edges fully supported

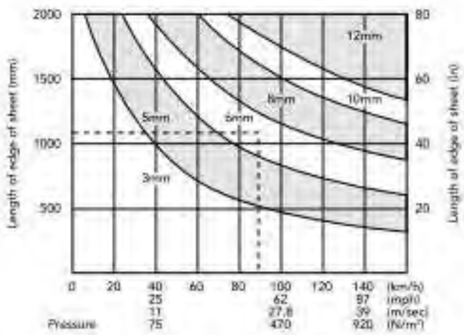


Figure 16 The recommended thicknesses of Perspex® for various wind loads when designing for rectangular windows, with all edges fully supported

NB: The figures for sheet thickness apply to areas bounded by the curves

Example of the use of Figure 16

To determine the thickness of Perspex® that must be used for a window 1100 x 1520 mm with a wind load of 90km/h (380 N/m2), determine the point of intersection between wind load line and shorter panel size (see the dotted line). The recommended thickness is 6 mm.

NB: At the recommended thickness, the sheet can deflect under full wind load and it is therefore important to use the appropriate depth of rebate as recommended in Table 4, to ensure the sheet remains firmly fixed in the frame.

http://www.perspex.co.uk/Perspex/media/Media/Technical%20Library/Material%20Safety%20Data sheets/Perspex_-_DESIGN_GUIDE.pdf

APPENDIX S

mellowcabs

To whom it may concern

Over the past few months Mellowcabs has dealt with Neil de Vos as a freelance industrial designer, and as a project partner in development of Mellowcab doors, and ingress/egress studies on our vehicles.

I can really recommend Neil to work on new products or improve existing ones, understanding of technology, materials and manufacturing methods to improve the design and usability of an item. This would also include:

- designing;
- modelling;
- testing;
- prototyping.

Neil has played a leading role in:

- Setting up team meetings to establish the design brief, including the concept, performance and production criteria;
- working on ideas as part of a team or developing design concepts using
- taking part in specialist or multidisciplinary team meetings;
- sketching initial design ideas;
- identifying the suitability and availability of materials;
- producing detailed, drawings and specifications using dedicated computer software (CAD) to produce design detailed ingress and egress studies.
- testing the design concept by computerised modelling or physical hands-on testing of models;
- researching materials, processes or market requirements;

I can highly recommend Neil de Vos for the work that he has performed.

DocuSigned by:

PJD du Preez

Managing Director

Mellowcabs

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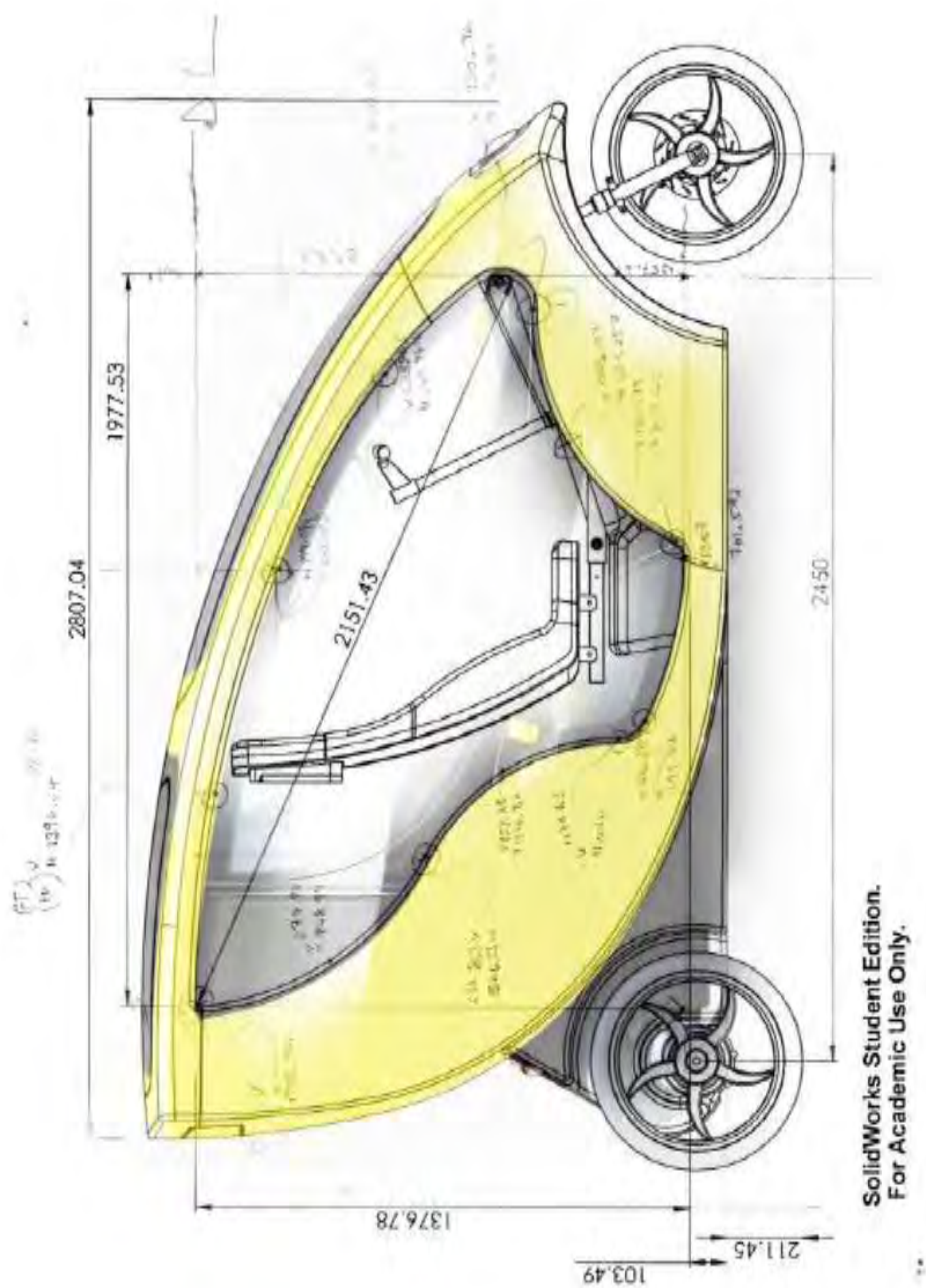
Tel: +27 21 8764340
Directors: P.J.D. du Preez

APPENDIX T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