4-1-2008

Mobility in China: a conceptual take on a personal vehicle for China in 2020 that enhances maneuverability

Jonathan Eziquiel-Shriro

MOBILITY IN CHINA: A CONCEPTUAL TAKE ON A PERSONAL VEHICLE FOR CHINA IN 2020 THAT ENHANCES MANEUVERABILTY

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A Thesis

Submitted to

the Graduate Faculty of

Rochester Institute of Technology

College of Imaging Arts and Sciences,

School of Design

in Fulfillment of the

Requirements for the

Degree of

Master of Fine Arts in Industrial Design

Rochester, NY
April 2008

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Except where reference is made to the work of others, the work described in this thesis is my own or was done in collaboration with my advisory committee. This thesis does not include proprietary or classified information.

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VITA

Jonathan Eziquiel-Shriro, son of Dr. Michael J. Shriro and Mrs. Aldegloria Eziquiel-Shriro was born February 16, 1978 in Rio de Janeiro, Brazil. He spent the first four years of his life there, moving to Ithaca, New York, when one of his two sisters needed open-heart surgery in Syracuse, New York. He graduated Ithaca High School in 1995 having only received his driver's license the day of his senior prom. In the fall of 1995, Jonathan enrolled at the University of Rochester, where he spent much of his time taking political history and architecture courses. His junior and senior years were spent investigating potential career options and were a time of study, travel and social interaction. In May 1999, he graduated with a Bachelors of Arts in Economics. Unconvinced that the world of finance was the right path to take, Jonathan took a hard look at the industrial design program at Rochester Institute of Technology. In the fall of 1999 Jonathan was accepted as a conditional undergraduate in the program. Upon completion of two years proving he had the requisite background and portfolio, Jonathan entered the Masters of Industrial Design program in the summer of 2001. Jonathan had been a member of the Rochester Student Chapter of the Industrial Designer's Society of America for three years and took part in international automobile design competitions. In Fall of 2002 and again in Fall 2003, Jonathan received 3rd and 2nd place awards for the design student category of the Motortrend Magazine International Design Competition. In fall of 2003 Jonathan's work on his thesis was entered in the Michelin Challenge Design Competition and was chosen to be a displayed finalist at the 2004 running of the North American International Auto Show, in Detroit Michigan.

THESIS ABSTRACT

MOBILITY IN CHINA: A CONCEPTUAL TAKE ON A PERSONAL VEHICLE FOR CHINA IN 2020 THAT ENHANCES MANEUVERABILTY

Jonathan Eziquiel-Shriro

Master of Industrial Design, May 28, 2008
(Bachelor of Economics, University of Rochester, 1999)

China has the largest projected automobile market in the world, expected to surpass the United States as the largest car market in the world by 2025. The combination of large population, a mass movement of citizens to cities, and a pollution crisis creates unique opportunities in China for automobile design. The first generations of Chinese to embrace the automobile have been attracted to them by the same values that have been embraced by the West such as prestige, a reflection of personal success, and a sense of freedom of movement. This attraction has given rise to traditional brands such as Buick, Audi and Mercedes Benz. However, as a new generation matures aware of China's problems presented by a growing number of automobiles, a shift is happening.

Awareness of ecological issues, as well as an acute sense of forthcoming issues with traffic density inside and surrounding China's vast metropolises, suggests future generations are more willing to embrace alternative solutions. China has a young automotive identity, currently relating to aesthetic qualities of certain brands. Without the same historical narrative that has informed the rise of the car in the West, China is poised to create one that can respond more acutely to its needs.

With fossil fuels the source of many potential problems in both pollution and cost of use, alternative energy vehicles will likely form the backbone of future growth of the automobile in China. Currently Toyota, GM, BMW, and Audi, to name a few, are actively pursuing alternative energy power plant designs. By 2020, alternative energy vehicles will make up a significant percentage of new vehicle sales in the Western world. Potential solutions come in the form of gas and diesel hybrids, all electric, hydrogen fuel cell and Hydrogen internal combustion engines.

For a car to successfully meet the needs of Chinese consumers, it will need to be both ecologically friendly and highly maneuverable to maximize use of the limited space available on congested streets. The simple act of making a U-turn on a narrow street in a conventional four-wheeled vehicle can cause traffic jams. Additionally, automation in future thoroughfares can reduce the space between individual automobiles, effectively placing more vehicles in less space. This thesis establishes the need for rethinking the physical footprint of the automobile in the context of the Chinese market and provides a framework for a new vehicle design.

Style manual or journal used:	Turabian's A Manual for Writers of Term Papers, Theses, and Dissertations 7th ed.
Computer software used:	Microsoft Word for Mac 2004 Adobe Illustrator CS3 & Adobe Photoshop CS3 Rhinoceros 3D 3.0 & Flamingo 1.0

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INTRODUCTION TO THE PROBLEM

Chapter 1

Problem Statement

China is just entering its own as a massively industrialized global power. As a result of its increased wealth and importance on the global stage, it has given rise to a new middle and upper class. Eager to show their success, these newly minted wealthy have taken to the Western sign of success – the automobile – with much enthusiasm. The car is now seen in China as a sign of one's personal success and freedom of mobility. As a result, traffic congestion is soaring to unprecedented levels, and pollution created by internal combustion vehicles is taking a massive environmental toll on China.

The objective of this thesis is the development of a set of guidelines for designing a car for China that would improve mobility and reduce pollution. Because of the relative immaturity of the Chinese automobile market, there is opportunity to create solutions that build on the West's century of automobile development and avoid pitfalls inherent in the current approach. The solutions created here combine the elements of emerging technologies with an eye toward the functional needs of Chinese consumers.

Research spanning several years has documented trends in the development of cars in China. Web sites have evolved over the past eight years that detail both the problems and potentials of future car designs, as well as provide insights into China's infrastructure and technology hurdles. Further study of existing automobile manufacturers and several automobile-related concerns reveals ideas for future concepts that offer glimpses of a cleaner and more efficient automotive future.

As more Chinese citizens gain access to material wealth and status, they look to Western brands as symbols of their own international status. Currently the most popular prestige brands are the same as found anywhere else in the world, with names such as Ferrari, BMW, Audi and Mercedes taking top honors. For the majority of consumers, international brands such as Ford, Buick and Volkswagen lead the sales.[1] Local brands in China are also growing in popularity as they improve the quality of their products.[2] Early attempts at domestic car manufacturing produced scores of low-quality knockoffs of successful western designs. Today Chinese domestic brands are reinventing themselves as quality alternatives to international brands and release new concept vehicles regularly to showcase their abilities.

Despite leaps in design and engineering quality, Chinese domestic cars mostly adhere to successful Western conventions. Car types such as the sedan, SUV, hatchback and minivan are the norm. Engines are similar in design to any internal combustion engines found globally. While adequate for the last century of development, China's rapid growth, lack of automotive culture, and urban density pose challenges that existing car types not ideally suited to solve. Future cars for the Chinese market need to offer compelling alternatives to existing car types and address the mounting issues. Pollution, congestion and driver-safety are enormous concerns, and will be secondary objectives I intend to address with this thesis.[3] Research into upcoming technologies reveals an opportunity to redesign cars for China's cities.

Chapter 2

Design Objective

The objective of this project is to design a vehicle that satisfies the issues of car ownership in crowded, developing urban areas as found in China’s tier 1 and tier 2 cities. A tier 1 city is typically a global center. A tier 2 city, however, is perhaps not as well known on the global stage, while still very important domestically. In the United States we typically consider New York and Los Angeles as tier 1s, while Sacramento, Milwaukee, and Raleigh are what business planners would refer to as tier 2.[4] China’s cities are swelling from the largest single mass migration in human history. While the density and pollution problems in Beijing, Shanghai and Hong Kong are well known, China has many other cities growing at breakneck speed and suffering from the same traffic-related maladies. Places like Shenzhen, Zhengzhou, and Jinan are high-density cities with millions of residents.[5]

With car ownership becoming an affordable luxury for millions of newly minted middle- and upper-class citizens, cities are choking with new drivers. Opportunities exist to design solutions that better address these concerns and seek to mitigate the problems created by current car designs.

Through the course of this thesis, research will outline the outstanding issues of private vehicle use in China, and highlight technologies that exist today or are under development and could offer potential solutions. The final deliverable will be a set of guidelines for creating a car that meets the needs of China's congested cities. Following those guidelines will be a concept that is a distillation of the concepts outlined.

Chapter 3

Definition of Terms

Common terms used in automotive design and engineering needing clarification follow:

ABS (Anti Lock Braking System) – A safety system found on most cars that modulates the pressure of brakes to give the driver more control in panic braking situations.

All Wheel Drive – A drive system in which mechanical power is transmitted from the drive shaft to all available wheels.

DARPA (Defense Advanced Research Projects Agency) – The name given to the U.S. Advanced Research Projects Agency during the 1980s. The name was later changed back to ARPA.

Drivetrain – In a vehicle, the term drivetrain or powertrain refers to the group of components that generate power and deliver it to the road surface, water, or air.

Electronic Stability Control – The generic term for systems designed to improve a vehicle's handling, particularly at the limits where the driver might lose control of the vehicle.

EV (Electric Vehicle) – A vehicle that moves under electric power only. Hybrid systems may provide electricity through use of fossil-fuel generators but are not mechanically linked to the wheels.

Ferdinand Porsche (1875-1951) – Austrian automotive engineer best known for designing the original Volkswagen Beetle and for his contributions to advanced German tank designs. Son Ferry Porsche is eponym for Porsche Automobiles.

Fisker Karma – A luxury hybrid sedan due to reach production in 2009.

Fossil Fuel – A hydrocarbon deposit, such as petroleum, coal, or natural gas, derived from living matter of a previous geologic time and used for fuel.

Fuel Cell – An electrochemical cell in which the energy of a reaction between a fuel, such as liquid hydrogen, and an oxidant, such as liquid oxygen, is converted directly into electrical energy.

Global Positioning System (GPS) – A system of satellites, computers, and receivers that is able to determine the latitude and longitude of a receiver on Earth by calculating the time difference for signals from different satellites to reach the receiver.

High Strength Steel – A low-alloy steel having a yield strength range of 50,000 to 100,000 pounds per square inch.

Hub Motor – An electric motor built inside of a wheel.

HVAC (Heating, Ventilation and Cooling) – The abbreviation for heating, ventilation, and air conditioning systems.

Internal Combustion – An engine, such as an automotive gasoline piston engine or a diesel, in which fuel is burned within the engine proper rather than in an external furnace, as in a steam engine.

Lane Departure Warning System – A mechanism designed to warn a driver when the vehicle begins to move out of its lane (unless a turn signal is on in that direction) on freeways and arterial roads.

Lead-Acid Battery – A storage battery in which the electrodes are grids of lead containing lead oxides that change in composition during charging and discharging, and the electrolyte is dilute sulfuric acid.

Lithium-Ion Battery – A type of rechargeable battery commonly used in consumer electronics with high energy density.

McLaren F1 – A former fastest-street-legal production car in the world.

Segway HT (Human Transporter) – The Segway is a self-propelled, two-wheeled scooter-like vehicle that can travel up to about 17 mph. Thanks to the use of gyroscopes and tilt sensors, when the passenger leans slightly forward, the Segway HT moves forward; when the passenger leans slightly backward, the scooter moves backward. It is said to use the same space as a pedestrian and can travel wherever a person can walk.

Smart Car – A mini-compact, two-seater automobile popular on crowded city streets of Europe since the late 1990s, which debuted domestically in January of 2008.

Supercar – A term coined by *Car* magazine in 1968 for any car that surpasses subjective standards of beauty, performance and design.

Swingarm – The main rear suspension component of vehicles that have a single rear wheel, such as a motorcycle.

Tesla Motors – A Silicon Valley automobile startup company focusing on the production of high performance, consumer-oriented electric vehicles.

Traction Control – On current production vehicles, traction control is typically (but not necessarily) an electro-hydraulic system designed to prevent loss of traction when the driver applies excessive throttle or steering.

Unsprung Weight – The weight of the various parts of a vehicle not carried on the springs, such as wheels, axles, and brakes.

Zero Emissions – An engine, motor, or other energy source that does not emit harmful compounds.

PART II

UNDERSTANDING THE ISSUES

Chapter 4

Traffic Congestion in China

> The keeping of face simplifies traffic to such an extent that drivers are basically free to do whatever they want on the road, and they know that they are likely to get little more than a fleeting, resentful stare in return. If there is space in front of you, then that space is yours unless someone gets there before you. How you get there is up to you. It is an image of chaos, yet it's a form of chaos with a harmonious edge.[6]

Traffic congestion in China is likely the most maddening system ever witnessed by Western eyes. Yet within the chaos there are remarkable reports that it flows and functions. The Bund Road in Shanghai is an example of this massive flow that occurs daily in China.

Figure 1. Shanghai Picture: Bund Road before improvement program near Huangpo River Landing Stage completed.

The amount of traffic that travels this road is far in excess of what Western drivers in congested cities such as Los Angeles or New York ever experience. Not surprisingly, these situations will remain the norm as private ownership of automobiles continues to increase.

Bicycle use had been the dominant form of wheeled transportation for decades, yet with the advent of broad arterial roads, they have come under fire from the Chinese government as being a hindrance to progress. As a result they have been incorporated into a center lane on pedestrian sidewalks. Pedestrian safety is further compromised by having to negotiate both bikes and motorbikes in pedestrian lanes, then having to cross the arterial roads to get from block to block.

Typical hazards for pedestrians in the cities of Jinan, which has a population of 3.3 million people, and Fushun with 1.4 million include:

- Pedestrians jumping tall, metal barriers between sidewalk and street in order to jaywalk, because city blocks are often more than half a mile long;
- Bicycles, motorbikes, and the latest newcomer—electric bikes—sharing sidewalks with pedestrians to provide more room on roadways for cars;
- Construction trucks roaring into cities at 7 or 8 p.m., just as students are finishing school and bicycling home;
- Haphazard law enforcement;
- Fading crosswalks because the cost of maintaining even this least expensive pedestrian crossing option is too high; and
- Dangerous behavior by pedestrians, whose lack of experience with motorized vehicles causes them to misjudge risk.[7]

With such risks an ongoing struggle, and the transportation officials reluctant to factor bicyclists into future transportation plans, there arises the opportunity to make better use of the existing roadways.

While statistics are officially considered unreliable by the Chinese government, it is reported that 100,000 people died in more than 450,000 traffic accidents during 2005, with 26% involving pedestrians and automobiles.[8] Furthermore, China's existing road network as of 2007 covered over 3.6 million kilometers of roads and 53,000 kilometers of expressways, which is second only to the United States and growing rapidly.

Violations of traffic rules such as speeding, running red lights and reversing on expressways are commonly observed practices throughout China. Some people have gone as far as to conclude that Chinese personal transportation should be limited and better public transit should be instituted. While valid, I chose not to pursue improving public transit as part of this thesis. The use of automobiles has a place in the fabric of a modern society. Careful consideration has to be made to the design of automobiles to better serve the individual, with a reduced impact on the group.

Inevitably, without comprehensive changes to both the public transportation systems and regulation of the roadways, any advances in personal transportation will be largely overshadowed by the congestion created by the increased numbers of vehicles. Current transportation systems in China are chaotic, with a mix of derelict diesel and other fossil fuel trains and buses operating on a network shared with the latest hybrid, fuel cell and electric vehicle concepts. The system is far from automated, and suffers from a lack of planning that extends beyond the mass production of more highways and rail lines when existing lines exceed capacity.

Addressing those concerns is beyond the scope of this document. Nevertheless the guidelines created seek to address a portion of this problem by effectively reducing the space occupied by single or two-occupant vehicles on a road. Adding more capacity to an already strained network will suffer diminishing returns if current vehicle sizes do not change. More efficient use of space will reap rewards in reducing the amount of road increasing projects, and allow public transit systems to better mesh with automobiles.

Chapter 5

Pollution and Environmental Concerns in China

A study taken in 2005 by the Worldwatch Institute, a Washington, D.C.-based nonprofit, indicates that China's production and consumption now leads the world in every sector. China is in the middle of the largest rural migration in human history with millions of its citizens moving into densely populated cities. As a result, national air quality has plummeted. Sixteen of the twenty worst polluted cities in the world are now in China.

In 2007, China overtook the United States as the world's largest emitter of greenhouse gases. While not the primary cause of greenhouse emissions, the transportation industry is the third largest producer, and the volume of gases produced increases with each new car put on the roads. Coal is the dominant producer of CO_2 followed by industrial sources.[9] Cars in China are not currently regulated to the same standards as their counterparts in Western nations, and fuel quality has only recently ceased to be a major issue for operating internal-combustion engines.

Researchers from the University of California at Berkley have recently discovered that Chinese CO_2 emissions are growing at a rate far greater than previously envisioned. Previous estimates put CO_2 growth at 4-5% annually, while new analysis indicates that amount could be as high as 11%. The most conservative forecast predicts that by 2010 China will have increased its carbon emissions by 600 million metric tons over its year 2000 production. Rationalized comparatively, that output growth is greater than either the UK or Germany's current level of CO_2 production.[10]

This massive growth in the levels of CO_2 production alone is cause for concern. The Chinese government is well aware of the challenges it faces, and has taken steps to institute strict fuel economy standards for new cars, tougher standards for factories and power plants and new regulation for power consumption.[11] However, even with pressure from China's leader, Wen Jiabao, progress is difficult to maintain. In May of 2008 he voiced his bitterness:

> Understanding is not adequate, responsibilities are unclear, measures are not complementary, policies are incomplete, investment doesn't arrive, and coordination is ineffective, if these problems are not turned around, it will be difficult to achieve any obvious progress.[12]

Truck use, which drives most of China's internal economic growth, is the largest transportation contributor to pollution. Diesel fuel in China is contaminated with 130 times the pollution-causing sulfur than the United States allows in on-road diesel. While car sales in China are now growing even faster than truck sales, trucks are by far the largest source of street-level pollution.[13] While diesel in the United States and Europe is largely lauded for its ability to deliver excellent economy with relatively low levels of CO_2, it is currently not a viable alternative to gasoline in China.

Soot and smog are the most common visible signs of greenhouse gas pollution. Acid rains are also increasingly prevalent as clouds saturated with oxides of nitrogen release their content over much of Southeast Asia. Nitrogen oxides such as NO2 and NO3 react with gasoline fumes to create photochemical smog and are produced in massive quantities from diesel usage. Tests by Chinese and American researchers found that diesel engines in buses and trucks accounted for 93% of nitrogen oxides from vehicles in China, and 97% of particles. Making the situation worse, many trucks and buses are overburdened and operate damaged smog controls, contributing to unusually large sizes and quantities of diesel soot.

New emissions standards for trucks are due to be implemented in 2010, and are at the “Euro 4” level which will mandate that exhausts are cleaner than existing air. However these 2010 standards are still five years behind contemporary European standards. The opportunities to further improve are limited by the quality of clean diesel fuel. To keep costs and inflation down, Chinese oil producers intentionally seek out low-grade crude oil. While economically appealing, this grade of crude oil is responsible for the high sulfur content found in Chinese fuels. The West seeks out lighter high-grade crude, which contains less naturally occurring sulfur. Refining sulfur out of lower-grade oil is possible, but it increases costs. Much of China’s truck driving population lives close to the poverty level, and increases in fuel costs would run many truckers out of business.

Chinese fuel and energy production is subject to pressures from both environmentalists and politicians to keep China’s economy growing. Opportunities to reduce emissions are met with resistance to maintain the pace of current growth. While strides are being made to ensure new vehicles, factories and power plants are compliant with global environmental protocols, not much is being done to remove the existing sources of pollution.

Nuclear power and renewable energy usage in China have grown considerably. The French firm of Areva, the world’s largest builder of nuclear reactors, forecasts that at least 50 new reactors will be built in China and India by 2030. A senior energy official told state media in March 2008 that the installed nuclear power capacity could be 50% greater than forecasted by 2020.[14] A renewable energy law was passed in 2006, encouraging power grid operators to purchase energy from registered renewable energy producers. While ambitious, this move indicates China is making a concerted effort to reduce its future dependency on fossil fuels while investing in clean alternative-energy sources.

With electric vehicles likely to be an instrumental part of China's mobile future, clean power generation is paramount to ensuring decreased pollution levels even as the economy grows and more wealth is created. The creation of hydrogen for fuel cells relies heavily on power consumption. Clean hydrogen generation requires a clean source of energy such as solar/wind power or a low waste power source like nuclear fission. Chinese clean-power generation is growing, yet 83% of its current needs are met with thermal power sources such as coal and gas. Of the remaining 17%, 14% comes from hydro, 2% from nuclear and the remaining 1% comes from a variety of sources, only .1% of which is wind.[15]

Chapter 6

Existing Personal Transport Systems in China

Before its economic boom of the last decade, most Chinese citizens utilized bicycles and motorbikes for their transportation needs. In 1988 there were more than 310 million registered bikes in use in China. During the same period, personal automobile usage was limited, with only 800,000 registered personal cars. By the end of 2005, registered private cars totaled 20 million. Today there are more than 40 million private cars in China, a number that continues growing aggressively every year. Bike usage however has reached a plateau.[16]

With ring roads and expressways becoming more common, and trips between large city blocks increasing in length, electric bikes have displaced many conventional bicycles. However due to a political disinterest in the bicycle and the “old-world” it represents, bikes have been forced off the road onto pedestrian thoroughfares. Electric bikes are treated the same as conventional bicycles and are loosely regulated to not become as fast or powerful as motorcycles. As a result, many of these electric bikes share roadway space with slower bikes and pedestrians.

In 2004 Beijing cancelled its requirement that bicycles be registered in a move to highlight the nation’s entry into “car society” and the demise of the bicycle as a “transportation tool.” At that time, car registrations in the city had already reached 2 million, half of the number of registered bikes. Beijing’s bike lanes were once a world standard in safety and usability. Today these lanes are overrun by drivers using them improperly, either for parking or to skirt around traffic. Officials claim the bike has a place in Chinese society but are quick to encourage the use of public transportation or private cars.

Electric bikes offer some advantages over conventional bikes, namely their ability to reduce travel time for short-distance trips, while being more economical and environmentally beneficial than automobiles. They travel 35% faster than their pedal-powered cousins and have a much larger range.[17] Their downsides include the need to draw power from an unclean electrical power grid, increased safety concerns, and their yearly consumption of lead-acid batteries. As power generation and battery technologies improve in both performance and environmental impact, electric bikes will likely retain an important role in China's economic development.

China is encouraging alternative-energy automobile production. Compressed Natural Gas (CNG) vehicles numbered over 6.5 million in 2005, and were ambitiously projected to grow to 50 million by 2020.[18] While not likely to affect personal car development, CNG vehicles are used in increasing number by state officials, buses and corporate fleet users. The relative cleanliness of CNG for internal combustion engines will help reduce the net pollution of new cars in China for the foreseeable future.

In a more web-generation-oriented push, the government-run Central China Television network has launched a web channel dedicated to Electric Vehicles (EVs). The channel covers topics such as EV news, interviews with officials and vehicle-producing companies, and the latest technological developments in electric vehicles. The idea behind the site is to encourage younger generations to learn and take interest in green vehicle initiatives.

Hybrid vehicles are making their debut in China, with local manufacturer FAW producing the Toyota Prius on license. While projected sales are small—limited to several thousand—it indicates an interest in obtaining green technologies for future automobile production. Chang'an Auto, China's fourth-largest carmaker, has responded to the Prius with mass production of a fuel-battery hybrid model expected to be marketed this year for about $20,000, $10,000 less than the Prius. Chang'an has set a target of producing 50,000 Jiexun-HEV hybrid cars in 2010.[19]

Several Chinese automobile companies have announced plans to develop hybrids, electric cars and fuel-cell technologies. The government is supporting the development of these technologies under its long-term science and technology plan, which was introduced in 2006. The domestic market is the primary target for these initiatives, with exports to the West to follow in the future. China’s green personal-transport market looks poised to reduce the burden the current system places on both fossil fuels and the environment. With a balance of electric bikes, small personal vehicles, green transit systems and environmentally sound personal cars, China’s transportation future could be a model of sustainability and socially conscious growth.

PART III

EXISTING ALTERNATIVE TRANSPORTATION CONCEPTS

Chapter 7

Alternative Wheel Layout Designs for Automotive Applications

The automobile as it exists today relies predominantly on four wheels, any combination of which is driven mechanically (or electro-mechanically in the case of EVs or hybrids). Four-wheeled vehicles offer a combination of stability, performance and a generally accepted aesthetic. However, in many situations four-wheeled vehicles are not used to capacity, using more space and resources than absolutely necessary to transport one-to-three occupants. Historically, other combinations of wheels have been explored with varying degrees of success, but none have yet proven to be as effective as a four-wheeled setup.

Motorcycles arrange their wheels in tandem, and the arrangement has proven to be quite effective at balancing a user, an engine and a light amount of cargo. The tandem arrangement of a motorcycle also confers advantages in maneuverability, allowing a motorcycle rider to place his vehicle in situations where a normal car would be far too wide to fit. Downsides of the motorcycle include its inherent instability when at a stop, its lack of elemental protection, and reduced crashworthiness in an accident.

Until very recently two-wheeled vehicles with wheels in parallel have not gone beyond the horse-drawn buggy. The Segway PT, introduced in December 2001, was one of the first vehicles to successfully marry electronics with this wheel arrangement. In its design, a sophisticated combination of sensors, gyroscopes, software and electric motors keeps a rider balanced in one place. By changing angle of lean, a rider can control fore and aft movement as well as rotation.

The Segway offers advantages in footprint and usage over conventional scooters and motorbikes. Its small size and low top speed allow it to be used on sidewalks and in parks, as well as indoors in warehouse spaces. The disadvantages of the Segway are its low top speed for motorway use, its upright standing position, which precludes its use for long distances, and its exposure to the elements.

Three-wheeled vehicles have existed as long as the car itself, with the 1885 Benz Patent Motorwagen being both the first automobile and the first three-wheeled vehicle.

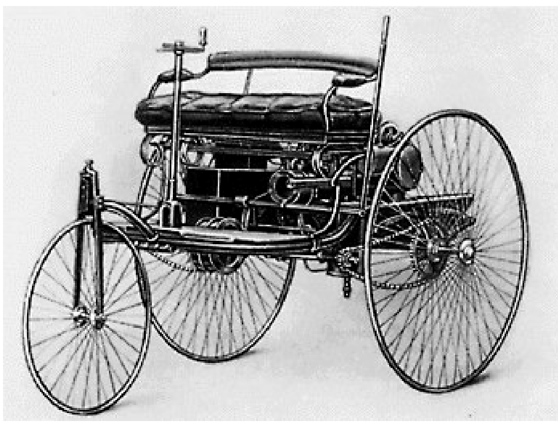

Figure 2. 1885 Benz Patent Motorwagen

The format used on this car is good in that it reduces the cost of a steering mechanism, but it is inherently unstable. However a configuration known as the tadpole that puts two wheels up front is superior for both aerodynamics and cornering. Stability is still a concern, as a three-wheeled vehicle at full speed will want to tip over instead of sliding during hard cornering.

Several solutions to this problem exist. The front wheels can be set up to lean into turns, reducing the instability of the car. If the vehicle is electric, the heavy battery components can be placed as low to the ground as possible, giving the vehicle a stable center of gravity. The aerodynamics of the tadpole configuration hews closer to ideal, as a tapering body creates less drag. This shape has been used in nature in birds, sharks, fish and most any animal that needs to propel itself without touching the ground.

Motorized three-wheelers have existed in China for several decades, and are often of the single wheel up front design. Motorized Rik Shaws are common in Southeast Asia to ferry people and goods cheaply. In the Europe and North America, three-wheeled vehicles have been introduced as sporting toys due to their inherent low weight, and ability to use motorcycle components. Bombardier Recreational Products, famous for their Sea-Doo line of jet skis, recently introduced a motorcycle-powered three-wheeler called the Can Am. Campagna makes a more car-like three-wheeled vehicle called the T-Rex.

The T-Rex is notable for being one of the most successful three-wheeled sporting vehicles in production today. The design is technologically simple, using the engine and rear suspension design from a motorcycle. A major advantage of this layout is the ability

Figure 3. 2006 Campagna T-Rex

to seat two passengers in tandem, and provide a measure of crash safety through use of an integrated roll-cage structure.

An interesting development in robotic propulsion suggests a viable alternative to the wheel and tire. A robot nicknamed the Ballbot, built by researchers at Carnegie Mellon University, moves and balances on a single rubber-coated metallic sphere. Ralph

Hollis of Carnegie Mellon explained his reason for pursuing the sphere motivation in the Ballbot:

> We wanted to create a robot that can maneuver easily and is tall enough to look you in the eye. Ballbot is tall and skinny, with a much higher center of gravity than traditional wheeled robots. Because it is omnidirectional, it can move easily in any direction without having to turn first.[20]

Figure 4. Ballbot at CMU

Ballbot uses a system of motorized rollers that act on the sphere–a system that is essentially an inverted mouse-ball drive–and remains upright through an interaction of motors acting upon the sphere. When not in motion, the Ballbot rests on three retractable legs. What is intriguing in the Ballbot design is the potential for increasing mobility in conventional car designs. The sphere-driven Ballbot can move in any direction before needing to turn its body. Installed on an automobile it could enhance the ability to maneuver in tight confines.

A recent winner of the Michelin Challenge Design competition used a similar concept for placing a two-passenger vehicle on top of a sphere, replacing the core of the Ballbot with a two-passenger cabin. The Audi Snook from German design student Tilmann Schlootz[21] explored this concept and won honors at the 2008 Michelin Challenge Design. While creating new challenges in engineering, the sphere-driven concept has its appeal in creating new ways to consider mobility.

Even Hollywood has embraced the aesthetic and mobile abilities of sphere vehicles in the 2004 film "I, Robot." In its vision of the near future, vehicles rode on spheres instead of tires. Visual effects envisaged vehicles able to perform feats far beyond the capabilities of conventional-wheeled cars.

Figure 5. Movie still from “I, Robot” showing sphere-driven Audi RSQ.

Chapter 8

Propulsion Systems

The first century of the car revolved around variations of the internal combustion (IC) engine. While electric cars existed in the early 20th century, battery technology limited their competitiveness with internal combustion (heretofore referred to as IC engines.) Advances have been made in engine designs, offering greater power and economy on ever less fuel. Nevertheless IC engines have their drawbacks: they take up volumes, concentrate a lot of mass, and require large cooling systems. Some power generated in an IC engine is lost to friction in the drivetrain before it reaches the wheels. Finally, more advanced control and safety systems rely heavily on electronics. Vehicle control systems such as Anti Lock Brakes and Active Suspension require heavy and complex additions to cars, adding weight and hurting potential economy.

Hybrid automobiles seek to capitalize on existing trusted mechanical technologies by combining them with electric motors and batteries. A Toyota Prius hybrid combines a small displacement IC engine with a generator and battery pack to deliver more efficient performance. However it still requires a

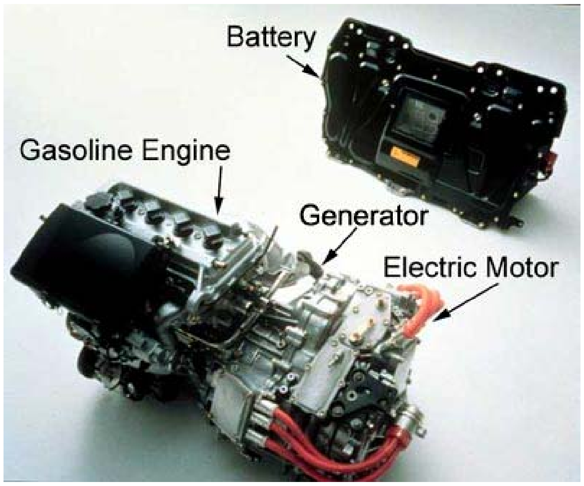

Figure 6. Toyota Prius hybrid drivetrain.

complete IC engine and drivetrain. While compact, even a small engine requires a dedicated footprint. A more ideal car design would disperse its necessary components at the lowest points of the car, improving weight distribution.

The Toyota Prius hybrid operates with an electric generator sandwiched between the transmission and IC engine. An electric motor operates on the transmission providing electric drive or drive assist depending on conditions. Hybrids that operate like this are known as parallel hybrids. These hybrids rely on IC engines to provide most of the motive energy for the car, and utilize the batteries and motor to improve economy. Chevrolet announced a more advanced hybrid concept, in which electric motors solely drive the car, and different energy sources provide the electricity.

The Volt, as the concept is called, is considered by GM to be a plug-in EV with a range extender. By making the power plant a modular and interchangeable system, multiple types of engine designs can be used. This general layout is considered a plug-in series hybrid because the engine drives the generator, which in turn charges the battery. At launch in 2010 the Volt will use either batteries or a small engine/generator with the batteries to provide power. Later versions are slated to offer diesel engines, all-ethanol IC engines or even hydrogen fuel cells when a hydrogen infrastructure is in place.

The future evolution of series hybrid vehicles hinges on the continued miniaturization of batteries of increasing energy density. Combining different electric propulsion technologies will optimize the design of cars into more efficient or even beautiful forms, depending on need. Smaller batteries can be located low in the chassis, improving stability and handling. Fuel cells can be shaped in a variety of ways, and the components necessary can be dispersed into optimal locations.

Both GM and Toyota have introduced fuel-cell-only concepts where the fuel cell technology is placed below the passenger cabin, as low to the ground as possible. More recently, the 2008 Pininfarina Sintesi concept took the idea of low-mounted fuel cell components further:

> This approach, which is known as "Liquid" Packaging, has overturned traditional volumetric balances, improving weight distribution and lowering the centre of gravity, which are important elements for driving dynamics.[22]

The Sintesi's approach to packaging highlights the potential flexibility of EV powertrains. The ability to separate car design from its traditional relationship of passenger space to mechanical space allows designers to rethink the form of automobiles, and create shapes previously unthinkable.

Figure 7. Cutaway of 2008 Pininfarina Sintensi Concept.

Electric motors in existing EVs are often placed inboard, needing a basic transmission to get power to the wheels. The Tesla sports car is typical of the current design of EVs. The motor is located low in the chassis, between the rear wheels. For its modest weight of 115 pounds, it delivers more power than the larger IC engine from its Lotus Elise parent car. In the Tesla, output from air-cooled AC induction motor is 248hp and 276lbs/ft of torque.[23] In comparison, the 189hp 2ZZ-GE engine in the Elise weighs 253lbs and requires oil for lubrication and water-cooling (both systems add weight and space to a car's design).[24] That translates to tangible benefits in performance with the benefit of zero fossil fuel use. Unfortunately, the lithium-ion battery pack in the Tesla adds a considerable 980lbs to the weight of the vehicle.[25] As a result the compact Tesla packages the battery pack above the electric motor, in the compartment an engine would normally be found.

More advanced motor designs place the motor inside the wheel itself. This type of motor, often known as a hub motor, is a design concept dating back to 1902. Ferdinand Porsche developed the first at the age of 27.[26] Ironically the vehicle that featured this motor design had a gasoline-fueled generator providing electricity, making it the true first hybrid. Hub motors are currently being experimented with in electric bikes, industrial vehicle applications and low-speed commercial vehicles like buses.[27]

Hub motor manufacturers are developing the concept for acceptance in automotive use. Current barriers to acceptance are inefficiency at low speeds and the weight issues of existing motor designs. Placing masses in wheels beyond the suspension components increases un-sprung weight. Increased un-sprung weight affects ride quality, handling and vehicle control. However, the weight and efficiency disadvantages of hub motor designs are vastly outweighed by their numerous advantages. Complex and costly safety systems such as ABS, Traction Control, Stability Control, and All Wheel Drive can be eliminated through the use of in-wheel hub motors.

Traditional hydraulic brakes can also be enhanced through use of hub motors. In low-speed deceleration a hub motor can improve the efficiency of brakes. From high speed a hub motor can serve as a generator, providing energy back to the batteries. This form of braking is known as regenerative braking, and is being introduced in many vehicles over the next couple of years to improve their efficiency. Regenerative braking is being introduced in Formula One racing in 2009 as a performance aid. Energy captured under braking will be released in short bursts under acceleration, reducing the amount of power the engine has to create to maintain current performance levels. However, in the case of the Kinetic Energy Response System (KERS), recovered energy is stored in a rotating flywheel instead of a conventional battery.[28]

In perhaps the most exciting breakthrough for future vehicle design, Michelin recently announced at the 2008 Paris Auto Show a new method of packaging both a hub motor and complete suspension. Dubbed the Active Wheel, this novel concept manages to eliminate the need for traditional chassis suspension through efficient design of shock absorbers and springs. Mounted inside the wheel, and combined with a hub motor, the Active Wheel seeks to eliminate the need for chassis-mounted suspension and drivetrain systems.

The Active Wheel system consists of the wheel and tire combination, an electric motor, an active suspension system, and disk braking system all integrated into a 95-pound package. Essentially, every element of the power train and suspension has been compacted. Smaller 14.4 pound electric motors can be used because there will be two to four of them sharing the load. Use of an electronically controlled active suspension system allows for a smaller, shorter travel suspension that can be optimized for road conditions.[29]

Aware of China's potential to leapfrog existing technologies used in Western cars, Michelin has partnered with a currently unnamed Chinese manufacturer as well as French automotive supplier Heuliez to develop the concept further. Commercially available vehicles equipped with the wheel are expected in 2011.

Combining hub motors with more radical packaging of energy-storage components allows car design to take new directions. Conventional drivetrain design limits the placement of people and their belongings, and increases the mass of an automobile. Heavier cars require more energy to move people and objects. As part of an effort to improve the efficiency and safety of vehicles, reducing weight is paramount. Exploration and continued development of alternative propulsion systems is essential in advancing the automobile, especially given the enormity of issues involved with increasing automotive ownership in China.

Chapter 9

Materials for Future Car Concepts

In the first century of the automobile, the vast majority of all cars were constructed in a variety of metals. Steel has long been the dominant material for manufacture, with alloys of aluminum or titanium becoming increasingly popular. As a construction material it has been popular for its relative abundance and ease of obtaining from ore rocks. Up to the mid-1970s, steel accounted for three-quarters of a car's total mass.[30] The use of iron and steel was widespread in every area of the car imaginable, including interiors. Advances in composites, alloy manufacturing, and creation of high tensile steel, reductions have been made in vehicle weight. Reduced structural weight is an important element of improving vehicle performance with less energy.

Steel use today accounts for two-thirds of a new car's weight.[31] Plastics and composites have taken hold in both interiors and exteriors and non-ferrous alloys are becoming more common in all potential areas. The first areas to receive plastic parts were the interiors and bumpers.[32] Aluminum has become an important material in reducing suspension-component weight and making lighter engine blocks. Other cutting-edge materials such as carbon fiber, kevlar and sheet molding compound have made their debut in performance automobiles in search of increased performance for less weight.[33] Ceramic brakes have offered increased brake performance and longer life while reducing un-sprung weight versus iron brake components.[34]

Nevertheless the use of steel is likely for the foreseeable future in automobile design due to its low cost per pound. Aluminum is advantageous for its good strength-to-weight ratio, yet its cost disadvantage renders it useful mostly for high-performance applications or any design that will have a comparatively high sales price. Advances in high-strength steel have reduced the weight and improved the strength for minimal additional cost.

Composites and plastics offer many advantages to metals, but the cost per pound of structural plastics far exceeds even the most exotic of alloys currently used in automotive manufacture. That however is the existing paradigm. With the price of steel and alloy manufacture rising, there will be drivers to overturn the existing paradigm and shift focus to plastics. In the document Plastics In Automotive Markets: Vision and Technology Roadmap, the plastic car is posited:

> By 2020, the automotive industry will have established plastics as the material of choice in the design of all major automotive components and systems.[35]

The significance of “all” in this document is significant for its assertion that no element of the car as we know it will be left unaffected. The American Plastics Council created the document in 2002 to help align interests in investment for future automobiles. Polymers have a diverse range of characteristics and are notable for:

- Strength, durability and light weight
- The ability to resist chemicals and environmental conditions
- The ability to tailor their visual properties (e.g., they can be made clear, translucent, or opaque)
- The ability to make them electrically or thermally conductive.
- Can be synthesized from a variety of renewable and non-renewable oil products

While car interiors are an environment already dominated by plastics, future developments in polymers for body panels can offset increased costs of body panels by removing the need for paint and paint shops. Plastics offer advantages in propulsion design, being especially promising in the development of fuel cells. The most exciting potential arena for plastics in automotive design is in semi-structural and structural components. Plastic bodies and chassis could eliminate many of the needs metal car bodies have, including integrated wiring. Wiring harnesses are perhaps the most crucial single component in new car manufacture. They are installed early in the actual build, and are expensive to modify or replace. A polymer chassis could incorporate wiring into its design, eliminating the need for a separate component. Modules for power, controls or even entertainment could be easily integrated and changed per need.

A Chinese car for 2020 would likely make use of advances in plastics to both reduce weight and deliver better performance. Composite secondary structures, body panels, interior surfaces and fuel cells will likely all feature prominently for their advanced characteristics. The ability to reduce design cycles, regionalize manufacturing and the consequent requirement for lower investments in machinery and equipment will likely make plastic a natural choice for future car production.

Chapter 10

Autonomous Cars

Decades ago, sweeping promises were made by both futurists and designers claiming automated cars and roadways would be with us by the 21st century. While there are no robot cars or automated lanes on highways yet, recent developments have shown the dream is not far from reality. Automation in cars has been a desirable goal for a multitude of reasons, the least of which is the removal of driver error from the equation. With over 70,000 road fatalities last year, China has aggressively sought to curb road fatalities that exceeded 100,000 deaths as recently as 2003.[36] China's congested roadways will continue to be lethal as more drivers with limited driving experience are given personal vehicles. Automation of cars in at least some environments offers the potential to increase efficiency and reduce accidents.

The modern history of autonomous cars began in 1977 in Japan. The Tsukuba Mechanical Engineering Lab created a robot car that tracked visual markers on a closed road at speeds up to 20 mph. In Germany in the early 1980s, Mercedes Benz developed a vehicle that used vision technology to navigate closed streets at 62 mph. Success with this program prompted the European Commission to fund the EUREKA Prometheus Project from 1987 to 1995. At a cost of 800 million Euros, the Prometheus Project achieved its first notable success in 1994, when two robotic prototypes navigated more than 1000 km of Parisian traffic at speeds up to 130 km/h.[37]

Remarkably, the VaMP and twin VITA-2 robot cars relied on vision-based technology solely to navigate, pass other cars, drive in convoys and make lane changes.

Global Positioning Systems, which can pinpoint the exact location of a vehicle down to centimeters, did not exist at this time. Later developments of driverless cars would come to rely on GPS to help navigate. The VaMP car, based on a Mercedes 500 S-class, later drove 2000 km from Munich to Copenhagen almost completely autonomously at speeds up to 175 km/h. Driver assistance was only used in construction areas. The work done in the Prometheus Project laid the foundation for all later advances in autonomous cars.[38]

In 2004 the Defense Advanced Research Projects Agency (DARPA) held the first of its Grand Challenges. A competition with cash prizes and funded by Congress, the Grand Challenge was created to further DARPA's mission to sponsor revolutionary, high-payoff research that bridges the gap between fundamental discoveries and their use for national security. In its first running, robot cars were created by a variety of institutions, corporations and other organizations to navigate a 150-mile course through the Mojave Desert in California. In its first year, none of the entrants successfully traveled farther than 12 miles.[39]

The October 2005 running of the Grand Challenge drew more entrants and yielded more promising results. While the 123-mile course had been changed from the previous year to use wider roads and fewer corners, all 23 finalists finished completely autonomously. The third Grand Challenge, commonly referred to as the Urban Challenge, tasked competitors to create vehicles to negotiate a 60-mile road course on the closed George Air Force Base in Victorville California. While less physically punishing than the 2004 and 2005 Grand

Figure 8."Stanley", winner in 2005.

Challenges in the desert, the Urban Challenge forced vehicles to interact with each other in a cluttered urban environment complete with four-way stop signs and traffic signals. Thirty manned vehicles were released into traffic to add to traffic density. Amazingly only one traffic vehicle was involved in an incident, a testament to both DARPA's and the contestants' focus on safety.

Automated highways systems (AHS) are an effort to construct special lanes on existing highways for use by automated vehicles. A successful demonstration of the concept occurred in 1997 outside of San Diego, where an eight-mile stretch of highway commuter lane was converted for use by specially prepared vehicles running automated technology.[40] Automated highways rely on a combination of magnets or special infrastructure in conjunction with partially autonomous vehicles. The existing designs for an AHS use designated acceleration lanes to join the automated traffic and have deceleration lanes to merge back with regular traffic. When leaving the system, the car checks to see if the driver is ready to take control of the vehicle. If a driver cannot take control, the system parks the car in a safely designated area.

As of 2007 a three-year project is underway to equip a special lane of Interstate 805 in San Diego with an automated system.[41] This will be the first such public use of its kind in the world. The advantages of an automated highway include the reduction of safe distances needed for individual vehicles to operate at high speeds. More vehicles can occupy much denser spaces since electronics can react faster and more consistently than human operators. Vehicles can also be driven safely at much higher speeds.

Manufacturers are well aware of both the challenges and advantages automation can bring to the roadway. In recent years, many have introduced an array of driver assistance products to new cars in efforts to build small steppingstones to complete automation. These mechanisms exist in three types: sensorial-informative, actuation-corrective and systemic.[42]

Sensorial-informative systems rely on sensors to rely information about the surrounding environment back to the driver. Examples include Lane Departure Warning Systems, parking proximity sensors, vehicle radar, and night vision. Actuation-Corrective systems modify a driver's instructions to execute them in a more effective way. These systems are sometimes considered active safety devices. Anti Lock Brakes are one of the oldest examples of these devices. Stability Control, Traction Control and All Wheel Drive are now common corrective systems. Systemic systems are more complex and feature some of the first publicly available autonomous systems. Automated parking and adaptive cruise control are the most publicized, with Lexus' self-parking system on the 2008 LS460 sedan famous for being able to parallel park itself.

The advent of these technologies, and the increased rate of their introduction into new cars, presages true autonomous cars by 2020. In the United States traffic congestion in major cities has reached a level where automation could reduce jams and save the country billions in lost hours of productivity and fossil fuels wasted idling. In China, where congestion in tier-2 cities already exceeds even the most congested American metropolises, automation could be a potential nation-saving device. While the advent of automated cars in very dense urban areas is still several decades off, alleviating the burden on highways and arterial roads could save China from increased congestion leading to denser urban centers. Having cars able to navigate themselves safely around other vehicles and pedestrians would likely decrease traffic fatalities as well.

PART IV

DESIGN DEVELOPMENT

Chapter 11

Guidelines for a Designing a Car for China 2020

The issues that China faces are compounding at an exponential rate. While there is an argument from both Chinese and Western scientists that suggests it would be best for China's government to limit the sale of private cars, it is inevitable that car ownership will continue to rise. Existing cars will have come to the end of their useful lives by 2020 and will need replacing as well. As a result, there needs to be a long-term approach to future car designs that takes existing issues into account. Current car design is heavily rooted in an industrialized approach that creates a heavy investment in machine tooling and support structure. Western traditions in industry can be surpassed for successful Chinese car manufacture.

With congestion a primary concern, a car design for China will need to reduce its potential footprint. Compact dimensions are ideal, yet if a car is too small, it will fail to connect with new Chinese consumers who are drawn to larger cars as status symbols. In a nod to this perception, many standard luxury cars sold globally, such as the 2009 Volvo S60 and Audi A4, are offered as long wheel base models exclusively in China. In a parallel with the United States, 83% of trips taken by car are taken with only 1.1 occupants per vehicle. The worldwide average is 1.8 occupants per vehicle. For a personal car in China, room for 3 occupants would likely serve many consumers well. A three-occupant vehicle could be packaged tighter than a traditional compact car, and reduce overall vehicle weight.

Enhancing driver visibility would be an aid in highly congested areas. In a three-occupant design vehicle, the driver can be located along the centerline. The McLaren F1 supercar of 1990 demonstrated the ability to package three passengers with a driver along centerline in a very compact car. The more recent 2007 Nissan Mixim concept features the same conceptual seating. Nissan's reason for placing a driver along centerline came from research of 15-to-17 year-old teenagers around the world. Hundreds of teenagers were surveyed and it was discovered that they were not interested in cars.[43] The design response from Nissan was to make the steering wheel like a video-game controller and put the driver's seat in the center of the cockpit. The Mixim has three permanent seats, with each passenger sitting offset behind the driver seat, with room for a fourth temporary passenger sitting between the two passenger seats.

Figure 9. Interior of 2007 Nissan Mixim Concept.

The packaging of the Mixim was made possible through use of an electric drivetrain. Batteries are sandwiched under the floor and hub motors free up chassis space for storage and occupants. As a result its outside dimensions are compact, at 12 feet in total length. A Smart Car, in comparison, measures 8 feet 10 inches from nose to tail.

With increased pollution a byproduct of increased congestion, a car for China should be predominantly electric. While plug-in electric cars rely on drawing power from a grid that may rely heavily on fossil-fuel energy production, series hybrids with clean-power generation ability can reduce the burden on a strained power grid. Fuel cells offer greater benefits of reducing pollution, but only if the hydrogen used is created in an ecologically friendly manner. Assuming battery technology improves at the current rate, electric cars will continue to make strides in efficiency. Today's lead-acid batteries in the hybrid Toyota Prius have already been surpassed by lithium-ion battery packs for the Tesla Roadster and upcoming series-hybrid Fisker Karma. Unlike the all-electric Tesla roadster, the Fisker Karma is a hybrid luxury sedan that maintains a small four cylinder engine under its low-slung hood for electric generation. Aiming for a 2009 launch, the Karma is an all-new design to be made in limited quantities in the United States. Further developments of battery technology will lead to longer-lasting and higher-capacity batteries, further reducing the load on the energy grid.

In congested situations, maneuverability can create options for drivers to place their automobile in tight confines. Small cars are inherently nimble and can navigate narrow streets with ease. However, they are less effective at higher speeds where their compact dimensions become a liability. A two-wheeled concept that scales up the concept of the Segway could offer one potential solution. Placing occupants between two large wheels in tandem stability would not be an issue; however ride comfort will likely be difficult to control.

A three-wheeled tadpole layout is advantageous for its reduced mass and reduced frictional loss. Additionally, the aerodynamic advantage of the teardrop improves efficiency at speed. Placing the front wheels far apart improves stability. However traditional steering systems rob space by requiring room for the wheels to swing inward. Steering racks also require space and create a draw on the overall power. To reduce part counts and eliminate a steering rack, elements of the Segway drive system could be used in conjunction with a third wheel. This would eliminate the need for large wheel wells, a steering rack and steering components.

The Segway “steers” by differential in wheel speed. Hub motors could be used effectively, with each wheel being independently driven. However, a fixed rear wheel would not allow the vehicle to properly rotate. Replacing a rear tire on an axle with a caster or a sphere would allow the vehicle to rotate in place, on the axis of the front wheels. To create a highly maneuverable and stable vehicle, a combination of fixed front wheels with a rear sphere would be ideal. The reduced complexity and cost of development would pay dividends for the manufacturer, and allow money to be invested in advanced materials and a luxurious interior.

Digitizing the interface from driver to car creates a need for advanced software to interpret driver inputs. As a result software would determine the desired direction and rate of change. Therefore the removal of mechanical connections facilitates systems where computer intelligence operates the car. This step is necessary to develop autonomous highways and self-driving automobiles. Current autonomous cars require electric motors to act on the steering, braking and other mechanical systems. In a digital car with hub motors, making a transition from driver input to autonomous control would be seamless and require no additional hardware.

To create the best solution for this thesis, guidelines to aid in the development of the car were created. Taken holistically, the following guidelines would be essential in creating a successful and beneficial car for China:

- Reduced mechanical complexity (i.e., no internal combustion engines, simplified steering components, compact suspension design and removal of ancillary safety systems).
- Small road-going footprint to occupy less space on the road and less space for parking/storage.
- Zero emissions in operation through the use of plug-in electric drivetrain. Fuel cells or battery power should be modular and used according to availability of hydrogen or clean electricity. Series hybrid drivetrains with internal combustion engines can be beneficial in regions lacking clean electricity generation.
- Highly maneuverable, nimble, and able to turn within its own length. Electric controls utilize software to interpolate driver direction and implement them through use of hub motors. Use of a sphere in rear and individual motors up front should allow the car to be capable of fast maneuvers impossible with current mechanical systems on four-wheeled cars.
- Room for three occupants with luggage area behind, with temporary jump seat for occasional fourth passenger. Flexible cargo area.

- Excellent visibility for the driver/operator with as close to a 360° field of view as possible. Rear view handled by cameras with integrated blind spot assistance.
- Autonomous ability for operation in congested traffic, with integrated controls for driving. Software will interpolate driver commands and provide tactile feedback and immediate response.
- Efficient use of mechanical space to allow for better packaging of occupants and safety structures.
- Low weight through use of advanced plastics, light alloys and reduced mechanical component count.
- Modular "corners" where hub motor, wheel/tire, suspension and braking are identical from side to side. Standardized components that can swap from side-to-side reduces development cost and simplifies manufacturing.
- Stable platform with good handling characteristics through placing the batteries or fuel cells low in the chassis.
- Aesthetically pleasing, smooth forms that harmonize with their surroundings.
- Speed-optimized aerodynamics through design of seamless body with tapering shape.

Chapter 12

The Car

The final car was designed to capture the mechanical requirements and combine them in a clean, aesthetically pleasing package. The forms are a combination of soft, flowing surfaces with crisp edging, balancing traditional expectations of what a car should be against the radical layout and packaging. The overall proportions emphasize the stable and dynamic nature of the car. The large front wheels pushed to the outer forward corners provide the car with a stable stance. A rising shoulder line combined with tall side surfaces suggest strength and solidity while the arc of the roofline connects the front to rear gracefully. The DLO (day light opening, a term used in car design studios) is tight, and narrow. This treatment renders the profile sporty, as smaller window areas are normally associated with more dynamic automobiles.

- The fixed wheels are 21 inches in diameter, giving a powerful stance to the nose. The wheels are pushed as far forward as possible to showcase the dynamic potential of the chassis. In any vehicle design, the relationship of the wheels to the overall form reveals the intended performance envelop of the car. In sporting automobiles such as BMWs or Ferrari, lengths are taken to ensure the wheels are located as close to the corners as possible, which in turn increases stability and handling potential. Luxury cars need to provide larger overhangs ahead or behind the wheels to incorporate elements such as a capacious trunk, or a larger engine.

- Fenders sweep tightly over the wheels and flow into a crisp, rising shoulder line tapering as it flows rearward. Broad shoulders give the impression of solidity, and safety.
- The broad, rounded nose is unadorned as a reflection of the simplicity of the drivetrain and mechanical design.
- Openings on either side of the nose are ringed by fiber optics, which become the headlights. The minimal cooling requirement of the batteries is met by these openings.
- The nose is short with minimal overhang, and the windshield starts just behind the front tires. A short hood covers access to the quick service points, and deforms for pedestrian safety. Twin ducts low and in front of each wheel supply air for cooling the hub motors.
- Roof pillars grow from the headlights and flow rearward to a reverse cut rear glass. They crown over the driver's central seating position to fall back gently to a tear-drop-shaped tail. Use of high-strength materials improves roll-over protection.
- The sphere is located inside the swing arm located under the rear of the car with the shell around it echoing the rounded form of the nose with a sharp bisecting line leading forward.
- Small winglets sprout from each side of the rear to create highly visible brake lights as well as provide aerodynamic stability.
- Rear glass extends down to the end point of the floor pan, maximizing rearward visibility.

CONCLUSION

Chapter 13

Conclusion of Study

When this thesis began in 2001, the natural first topic of design study was improving the bicycle. With China being famous for its bicycle use at the time, it seemed a natural place to start explorations. From this basic notion, a reconfiguring of two-wheeled transport with the Segway as a start led to scaling up the balancing technology into a proper land vehicle. The results of this initial study led to the development of parallel-wheel concepts.

Parallel-wheeled vehicle (Appendix B, images 10-13) design offers the advantages of a stable platform and the ability to seat riders in tandem, as in a conventional car. Through a series of sketch explorations, initial concepts of the parallel-wheel theme were developed. While promising, the questions of balance and utility prompted a deeper dive into what a car for China would require. Exploring the simple question of how many wheels are necessary, lead to the addition of a third wheel -- in the form of a caster. The simple addition of a rear caster changed the car completely, providing stability and reducing the reliance on sophisticated balancing systems to keep the car upright.

Further design development was promising, but ultimately fell victim to a lack of understanding about the particulars of three-wheeled vehicle design. For the model displayed at the 2004 Detroit auto show, the basic concept was modified to have two large casters in the back, on a skateboard chassis that carried fuel-cell technology. The "skateboard" is one mooted by GM in 2003. The concept is to place all the vital components of a vehicle in a flat chassis underneath the main body. In GM's interpretation, the body could then be an element that changes – a roadster body on the weekend could be replaced with a wagon body for the week.

During the model development, the proposed body became a slab-sided box due to inexperience with sculpting agents. In essence, this stage of the concept development was driven in large part by the materials available to work with, education in different modeling materials, and the January 2004 deadline of the Detroit auto show.

After taking a four-year hiatus from the project, there was opportunity to reflect on design successes and failures of the original concept. What was successful was the concept of a highly agile, compact vehicle. What failed to meet the criteria originally set forth were the unappealing boxy body, and the awkward use of large casters in the rear. The notion of maneuverability needed further exploration, but in the context of real automotive design. After a lengthy series of sketch explorations and research into alternatives to improving mobility, it was clear that a more integrated approach would serve the needs of the original criteria much better.

In the intervening four-year period, the proliferation of articles, research data and coverage of Chinese cars proved to be invaluable in shaping the final outcome. While originally assumptions were made on limited data and conjecture, the final development benefited from four years of auto shows, technological advances and trend research.

Sketch refinement of the model in figure 28 led back to the original idea of a three-wheeled vehicle, with the slab-sided body replaced by a more sophisticated teardrop form. The exposed wheels were integrated into the body, and the windshield was raked back to give the shape more dynamism. The overall size of the final concept (figure

32) is comparable to existing city car concepts, while the simplicity of the form is in keeping with existing design trends.

The final design solution demonstrates how thoughtful integration of new technologies can lead to paradigm-shifting solutions. In a place as complex and congested as the roads of China, intelligently designed vehicles that recapture road space through intelligent packaging can help improve the experience of automobile use, as well as allow drivers to share space more effectively.

Chapter 14

Study Accomplishment

The accomplishments of this thesis are the creation of guidelines for designing a car with China's congested cities in mind. These principles were successfully applied to the design of an automobile designed with Chinese consumers in mind. The final form is a visual example of the distillation of new technologies and thinking into a new automobile concept.

This thesis streamlined and condensed several years of research into a concise list of design considerations which can be used by other designers or stylists in further development of this car type. Consideration of the materials necessary and the packaging of passengers can be undertaken with the existing 3D data providing baseline dimensions.

Chapter 15

Areas for Future Study

In the future, it would be advantageous to create a design that captures a specific brand's attributes. In automotive design studios, a study of a brand's attributes, weighed against specific targets for the project, determine the nature of its styling. Given the framework of a brand, style elements would be added to create a connection with a buyer. Research done during the course of this project did show that Chinese consumers are extremely brand conscious. This creates an opportunity to restyle the existing form with attributes of a desirable brand. For the Chinese market this could be either a local manufacturer or a global builder such as Audi, Nissan or Chevrolet. In Appendix C there are sketch examples of a variation of this project presented with Nissan-brand attributes.

Another potential avenue for exploration is the study of advanced electronics in the function of the vehicle. Electric vehicles create a natural starting point for introducing devices that respond to sensorial input about a driver, and could utilize that data to improve the cabin environment. Immersive electronics could reduce the saturation of information presented to the driver, and free an operator from distractions. Opportunities in advancing interior design also exist in material choices for the cabin environment, design of HVAC systems, and the integration of safety systems.

Further research into the production feasibility of the rear sphere would benefit from an in-depth collaborative study with engineers to ascertain the opportunities and potential issues with its design. The Ballbot was designed to operate on smooth surfaces at low speeds, while the sphere in the car will exist in a much harsher environment. While suspension design is based on proven swing arms from motorcycles, the sphere itself will be subjected to bumps, potholes, unimproved roads and road debris. How exactly it will cope with situations needs further investigation. The design of the sphere tire and the cradle that holds it in place are complex enough to be the subjects of their own research for an automotive application. Nevertheless, if its design was not production feasible in a reasonable span of time (before the year 2020), then alternative solutions do exist. Replacing the rear sphere with a conventional wheel, and using Michelin Active Wheel technology in place of the fixed front wheels would make this vehicle feasible today using existing technology.

Opportunity also exists to merge public transportation with advanced personal transportation concepts to create a complete system. The use of public transportation in China is encouraged, yet not to the degree that personal automobile ownership has been. A system that better serves the needs of the public, using both personal transport and public transportation, might be an outgrowth of this study, and offer potential refinements to the final concept here.

A final area for design refinement would be the incorporation of bicycle usage into the final design. An automobile that worked with bicycle users, or provided a bridge between long distance travel with a car and short distance bike trips could enhance the experience of transit. Bicycle use has been successful for China’s growth into a modern society. Truly successful transportation solutions will likely work with bicyclists to reduce congestion while enhancing personal mobility.

This thesis illustrates the development of one design choice given a set of chosen issues to address. These guidelines could be used in development of cars for different niches or in other countries with similar issues. The key connection would be designing cars with congested urban areas in mind. With car ownership growing in many developing nations, opportunity exists to translate these findings into a car appropriate for rapidly developing global cities like Rio de Janeiro, Mumbai or Jakarta.

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Appendix A

The following images show the final model of the car and highlight its features. The car was designed with dense urban areas in mind throughout the whole design process and incorporates the guidelines developed to design a car for China for the year 2020. The final model was modeled in Rhinoceros 3D 3.0 software and rendered in Flamingo 1.0.

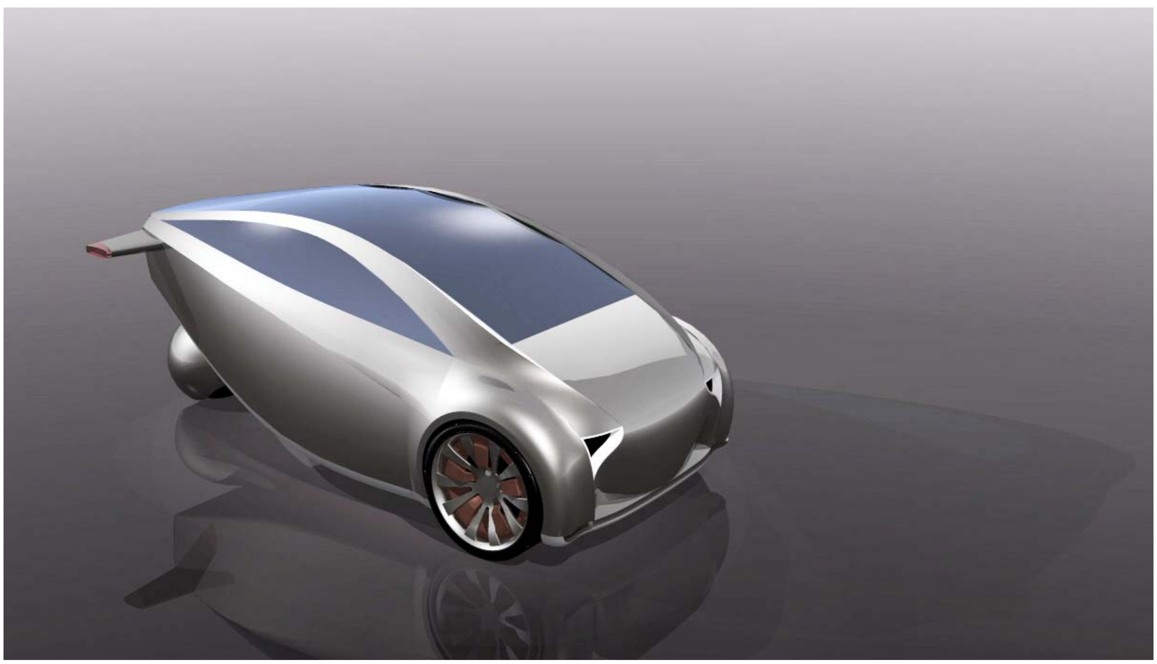

Figure 10. Final car rendering, high front ¾ view

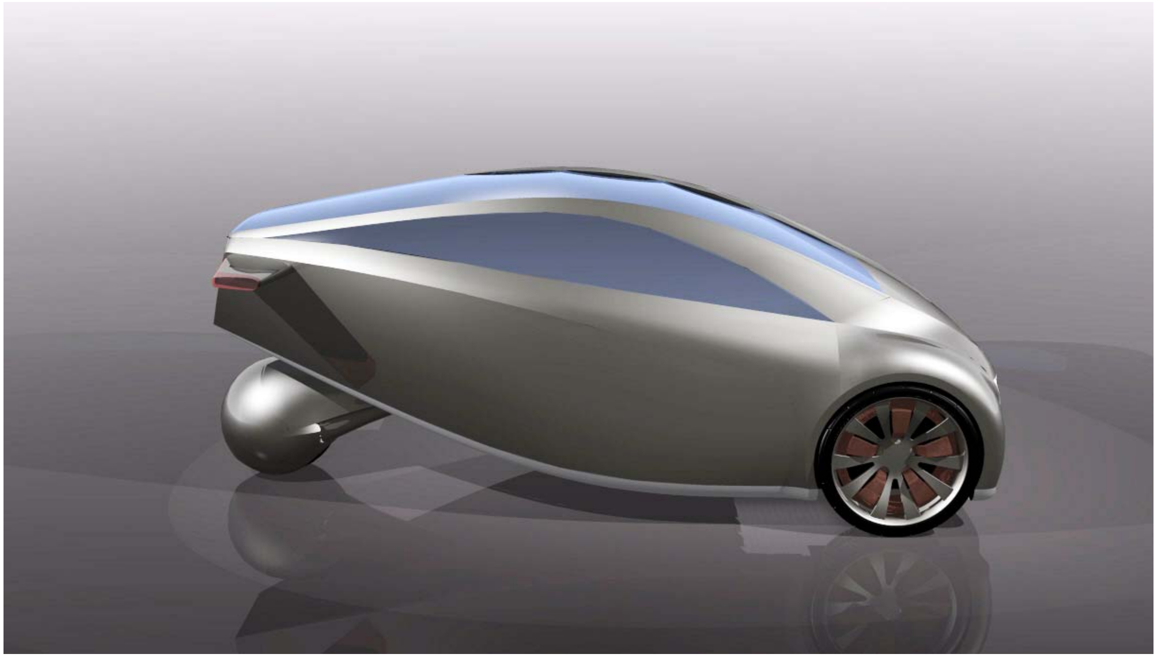

Figure 11. Side profile of final car model. Overall length 142 inches.

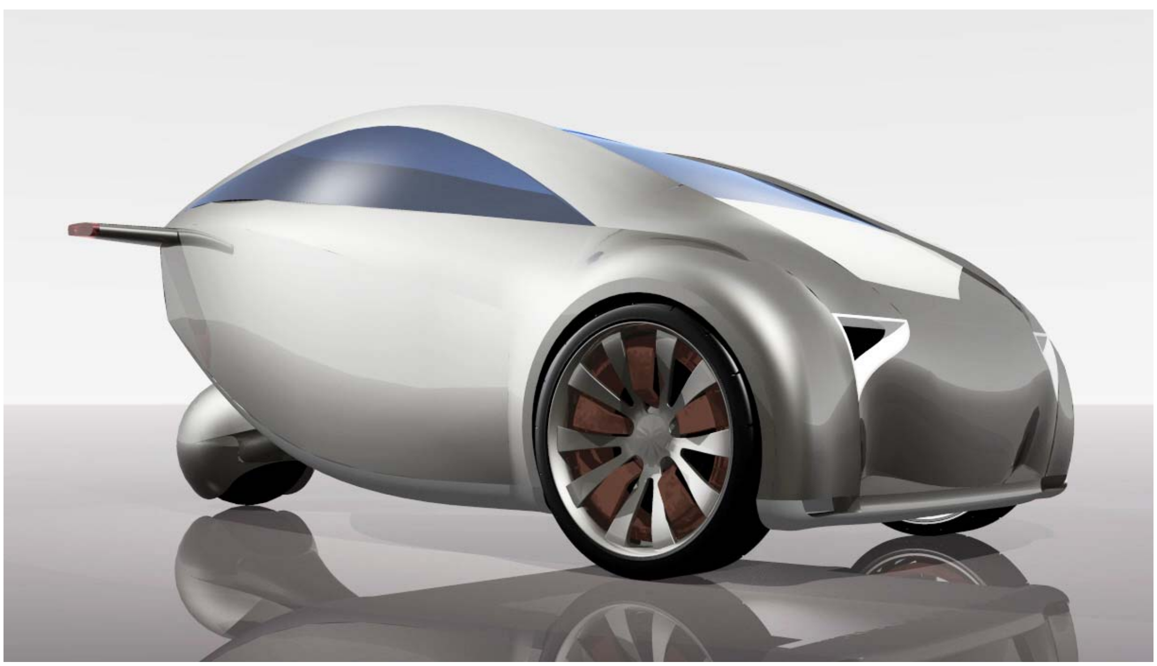

Figure 12. Low front ¾ of model emphasizing powerful stance of wheel/tire package.

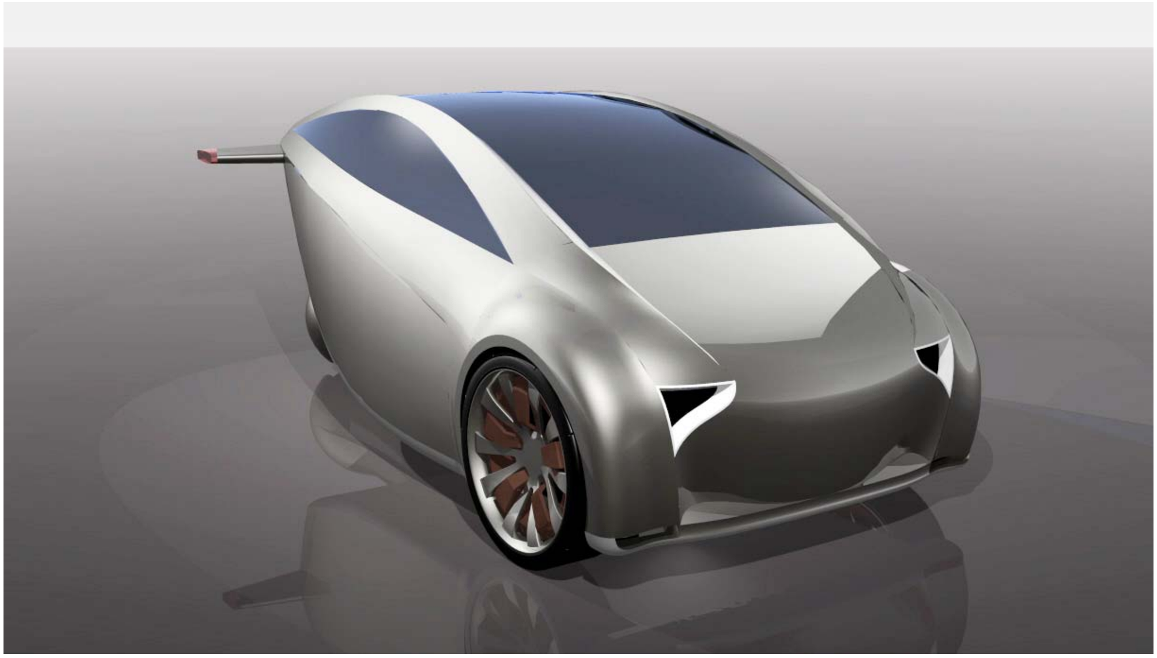

Figure 13. High front ¾ showing cooling/headlight components.

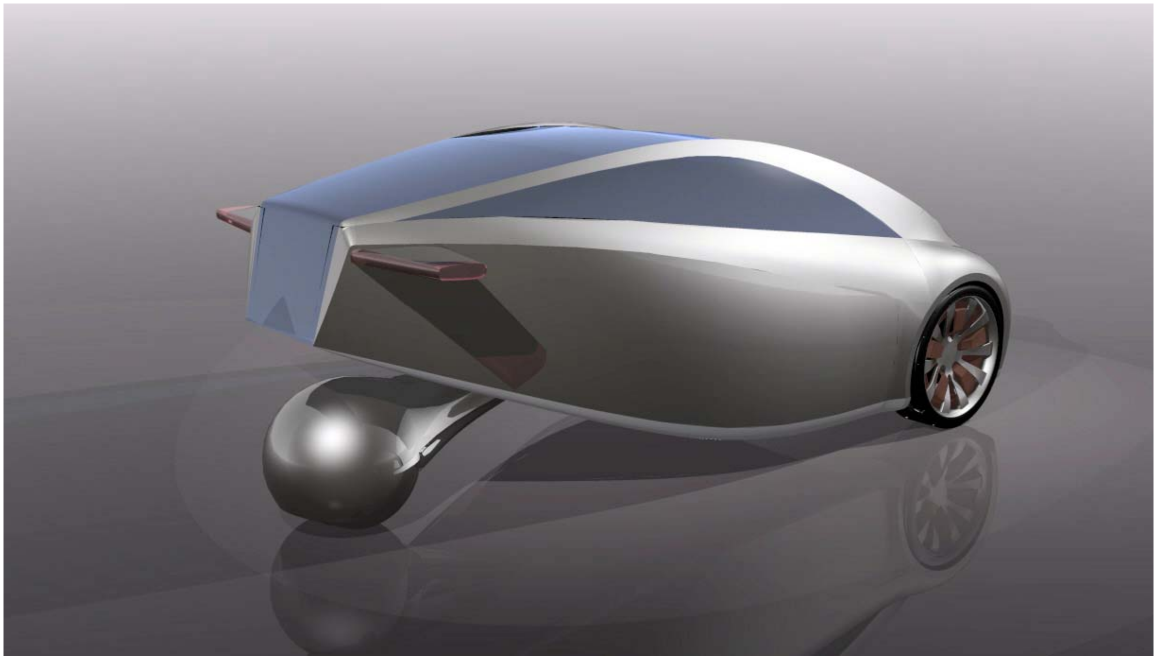

Figure 14. High rear ¾ view showing rear glass, sphere location.

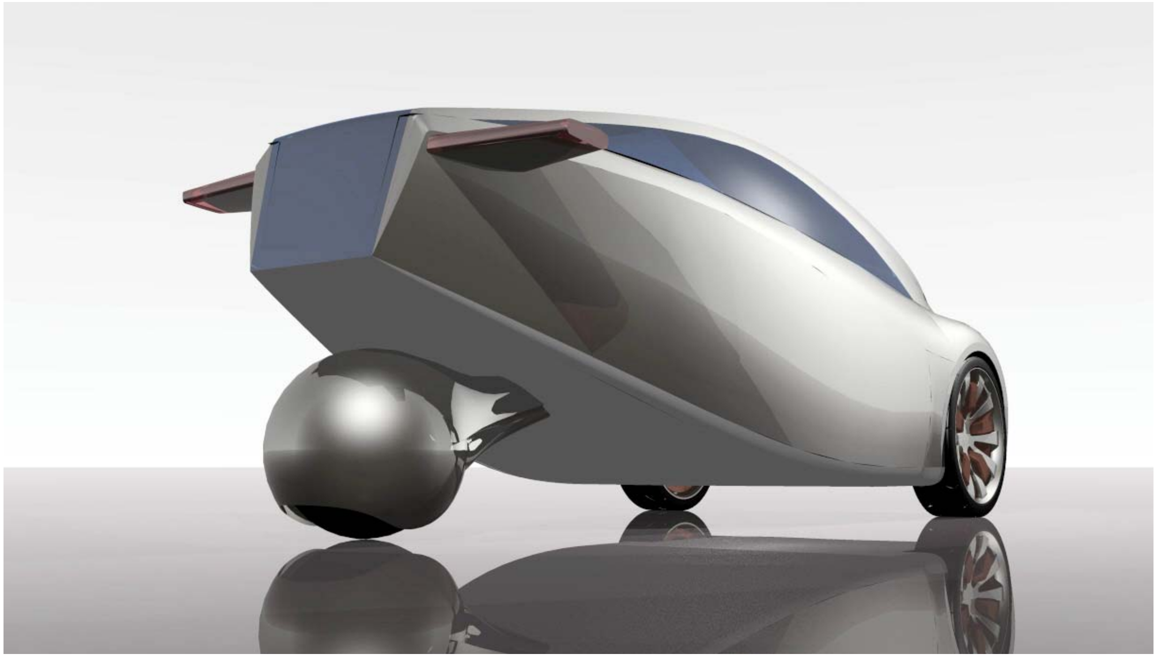

Figure 15. Low rear ¾ view.

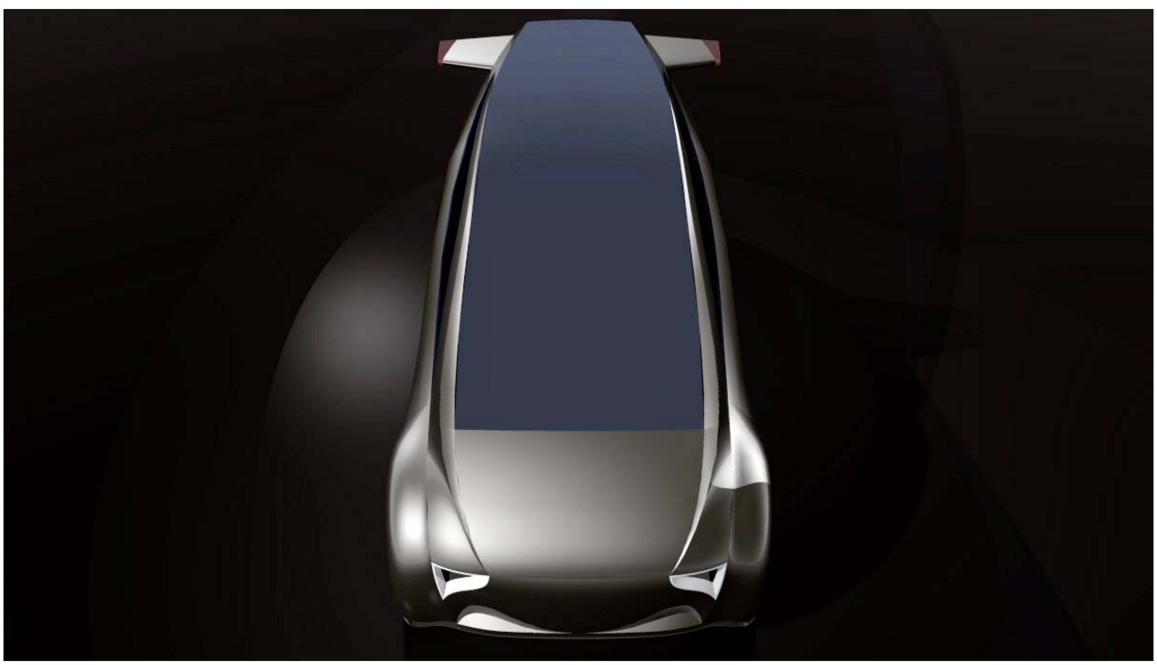

Figure 16. High forward front view.

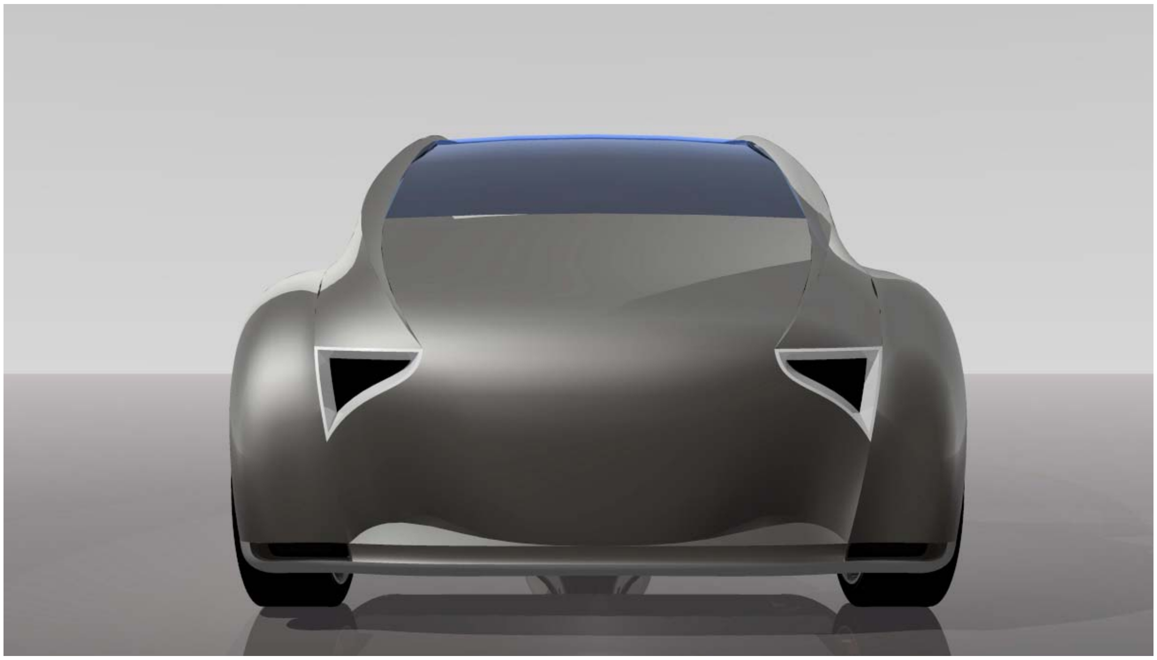

Figure 17. Front view.

Figure 18. Wheel, tire and motor.

Appendix B

The following sketches, renderings and photographs illustrate the design development of the project from its inception as a two-wheeled vehicle, through the 3D renn shape model to the final form shown in appendix A. Design started at basic parallel wheeled vehicle, evolved to a 3-wheeler, then a 4-wheeler. Model construction began at this point. The sketches following show the revisit of the 3-wheel concept, its evolution, and a rough Rhinoceros 3D model.

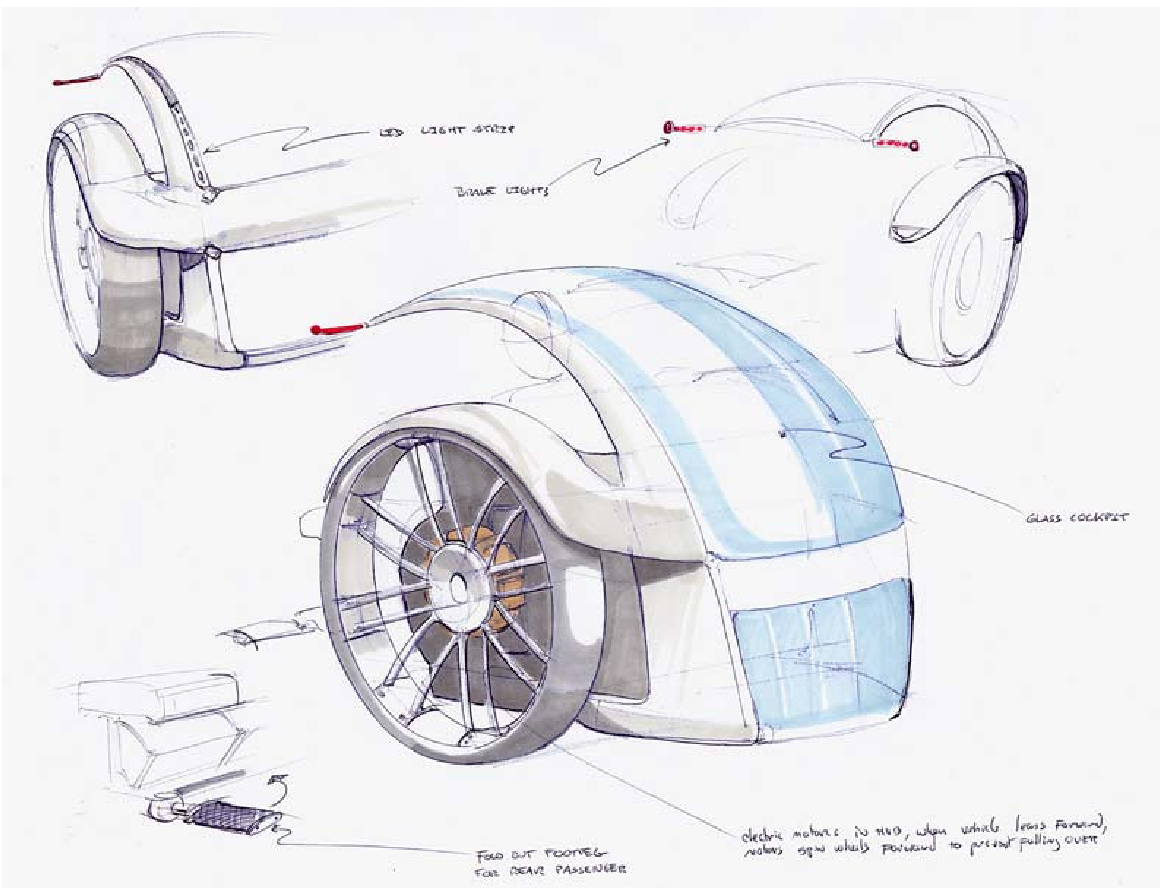

Figure 19. Initial concept studies of parallel-wheeled vehicle.

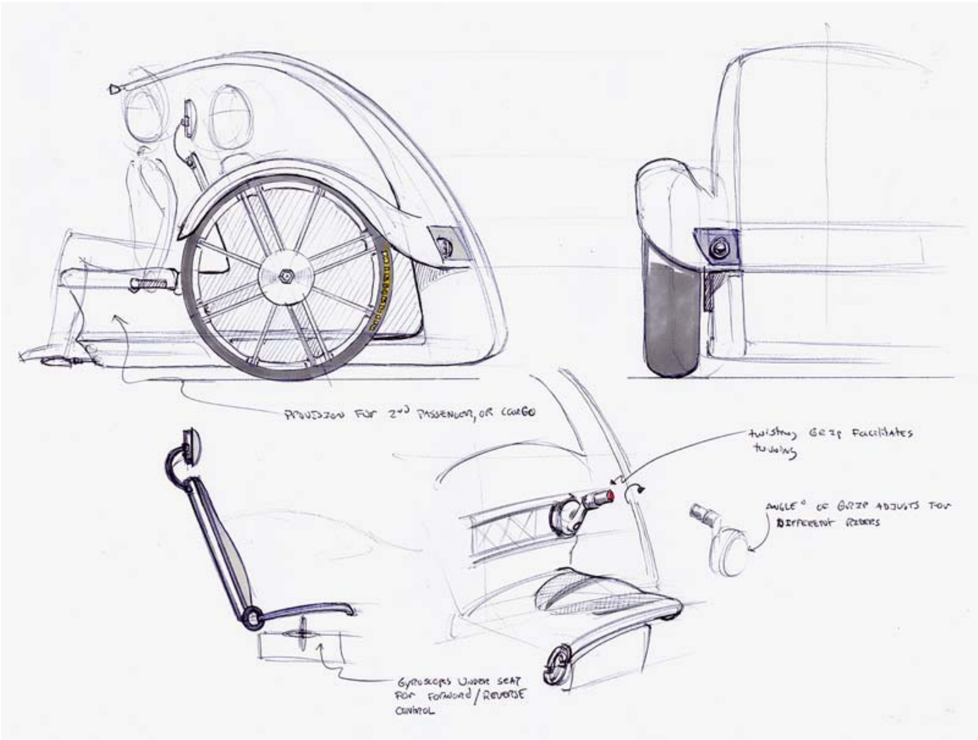

Figure 20. Detail sketches of initial parallel-wheeled concept.

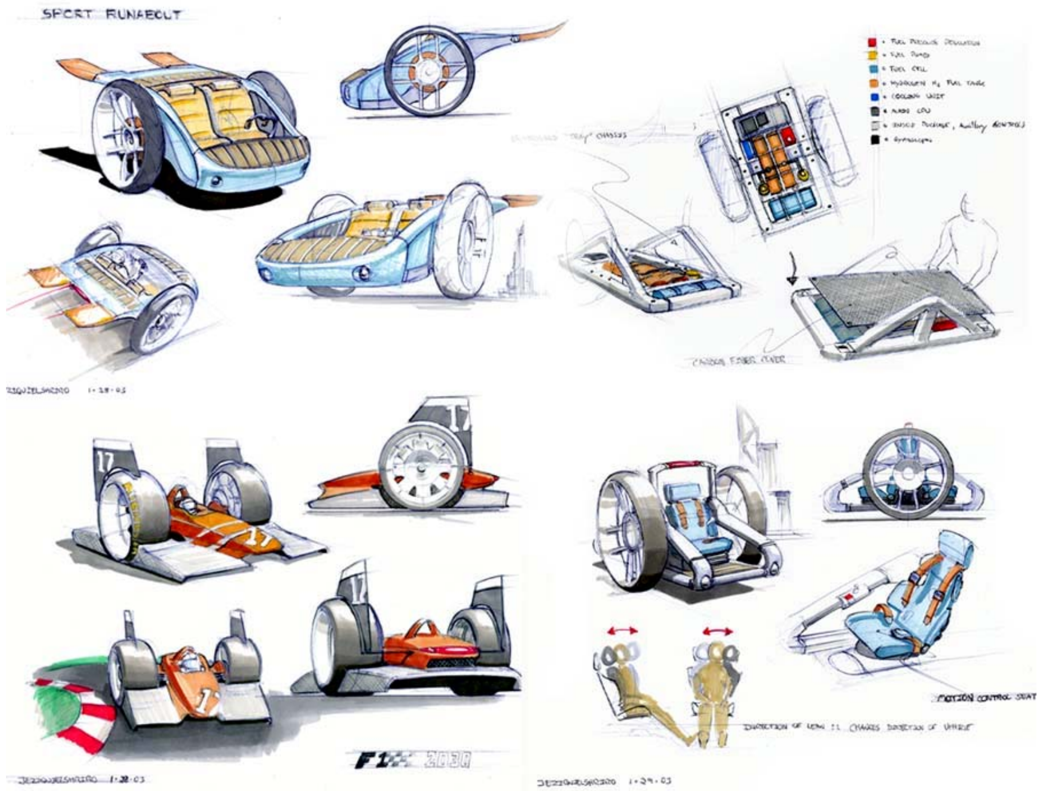

Figure 21. Concept sketches of parallel wheeled vehicle concepts: Roadster, Utility Chair and Racer.

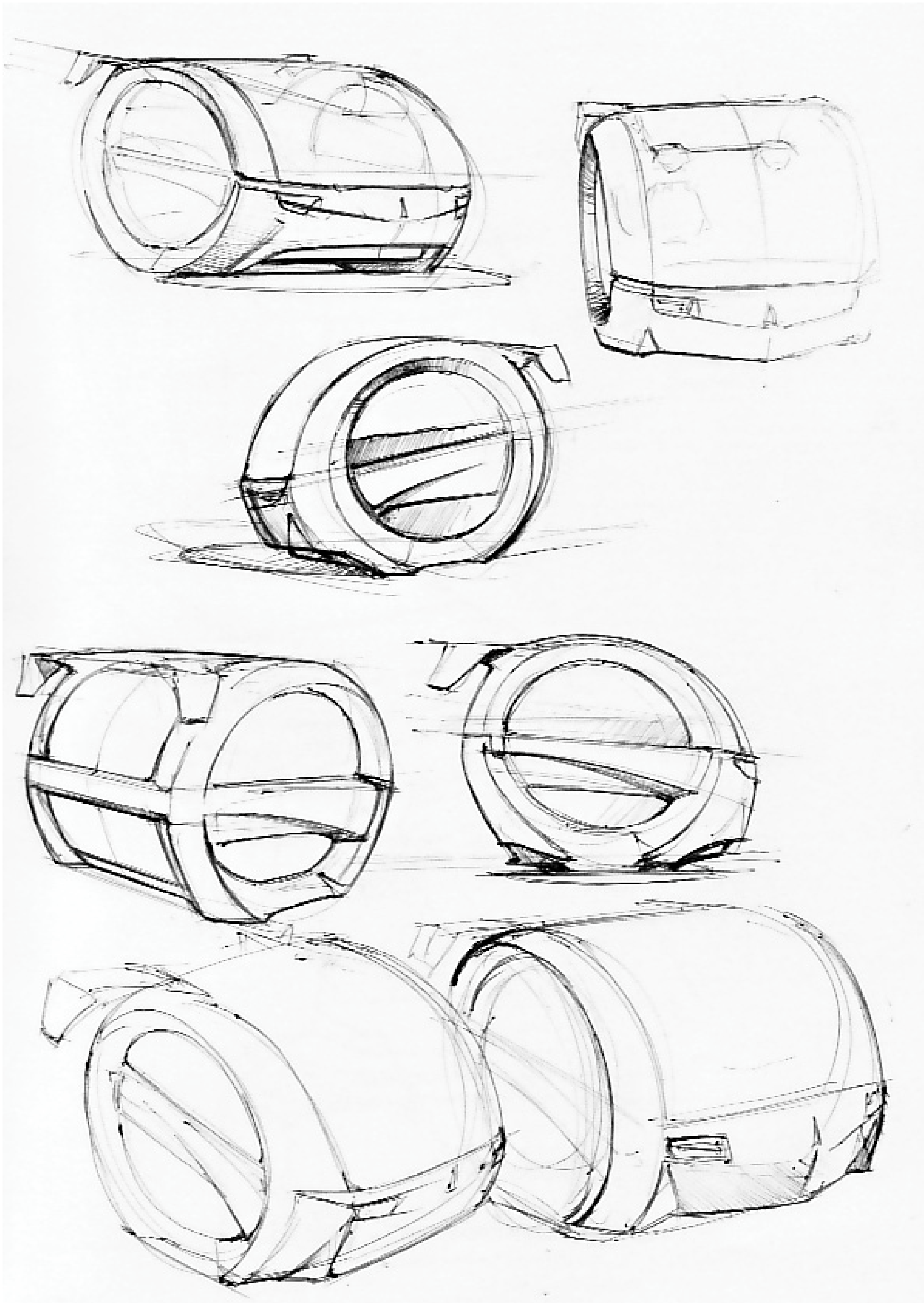

Figure 22. Parallel-wheeled concept with full circumference wheel integrated into body.

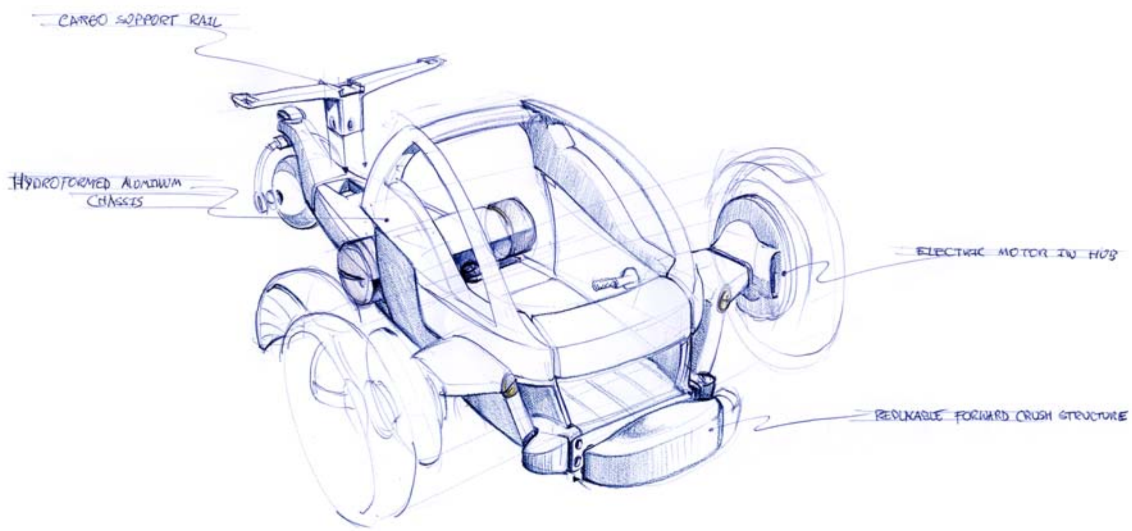

Figure 23. Early sketch of 3 wheeled vehicle concept, with sphere caster**.**

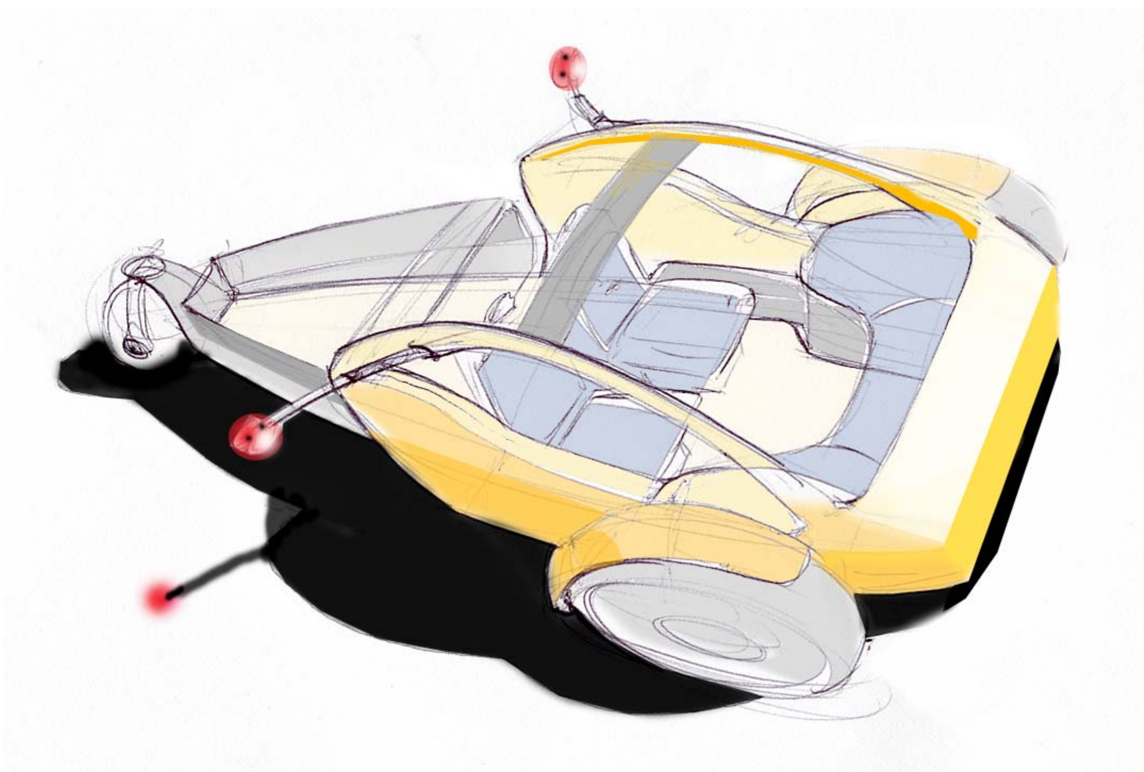

Figure 24. 3-wheeler sketch, used for application to Michelin Challenge Design.

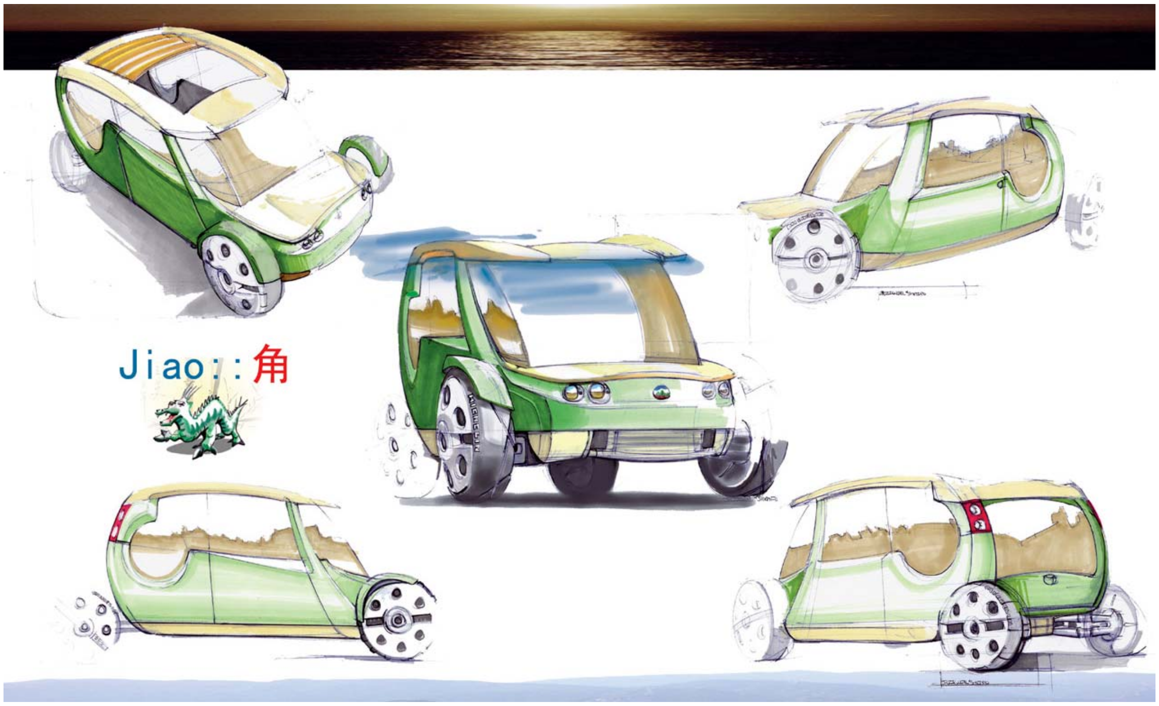

Figure 25. Development sketch of “Jiao” 4 wheeled vehicle. Caster replaced by articulating rear wheels.

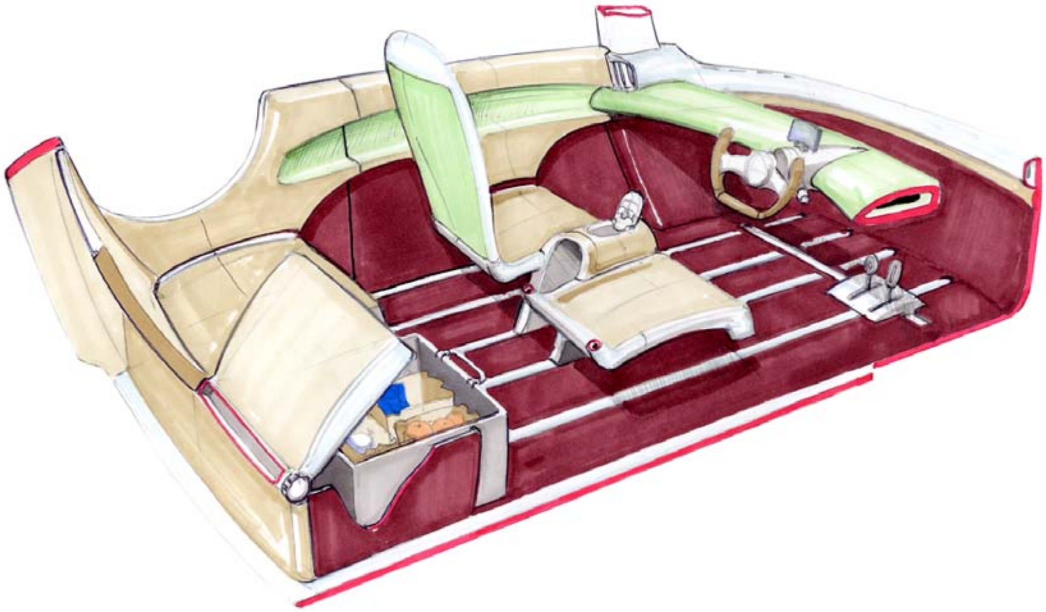

Figure 26. Interior sketch of “Jiao” concept development.

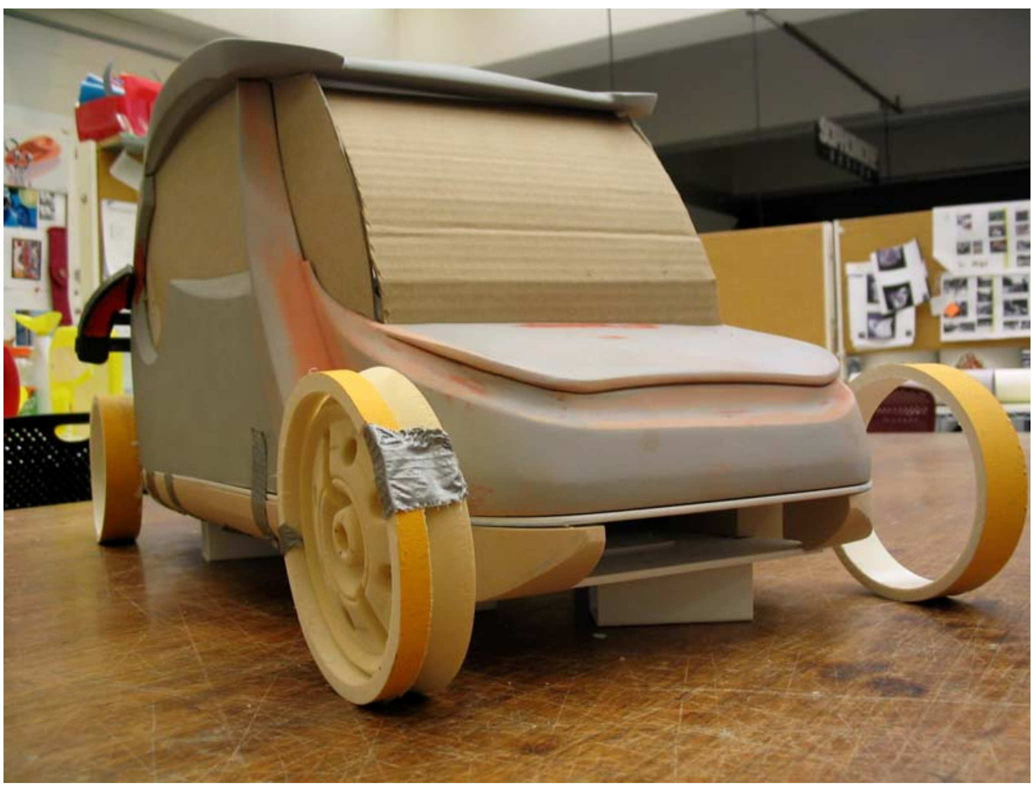

Figure 27. Jiao model in development at RIT.

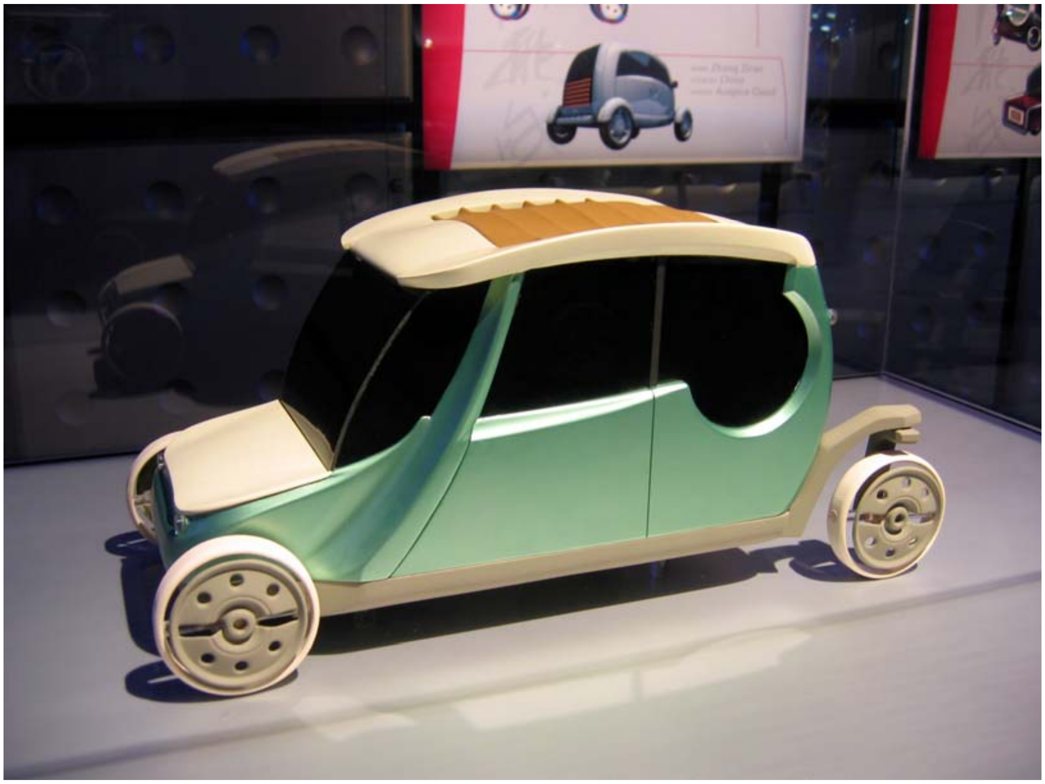

Figure 28. Jiao model on display at Michelin Challenge Design, Detroit Auto Show 2004.

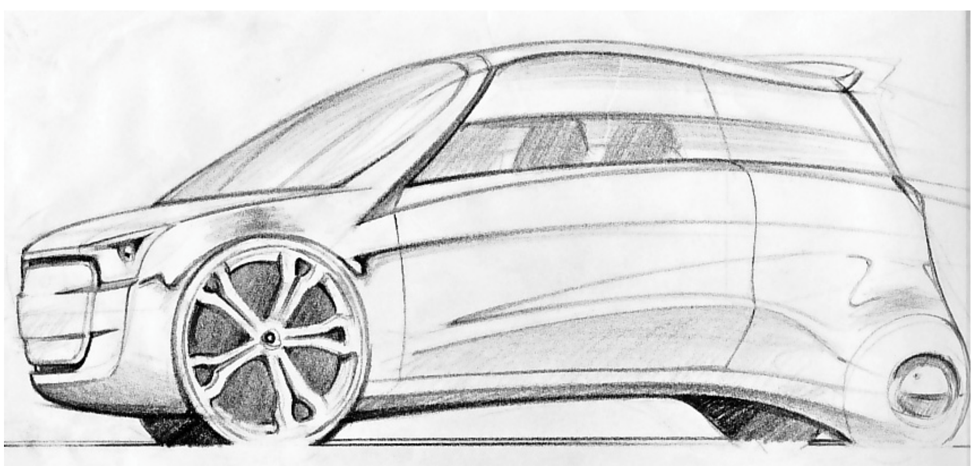

Figure 29. Early Sphere application to rear of hatchback form.

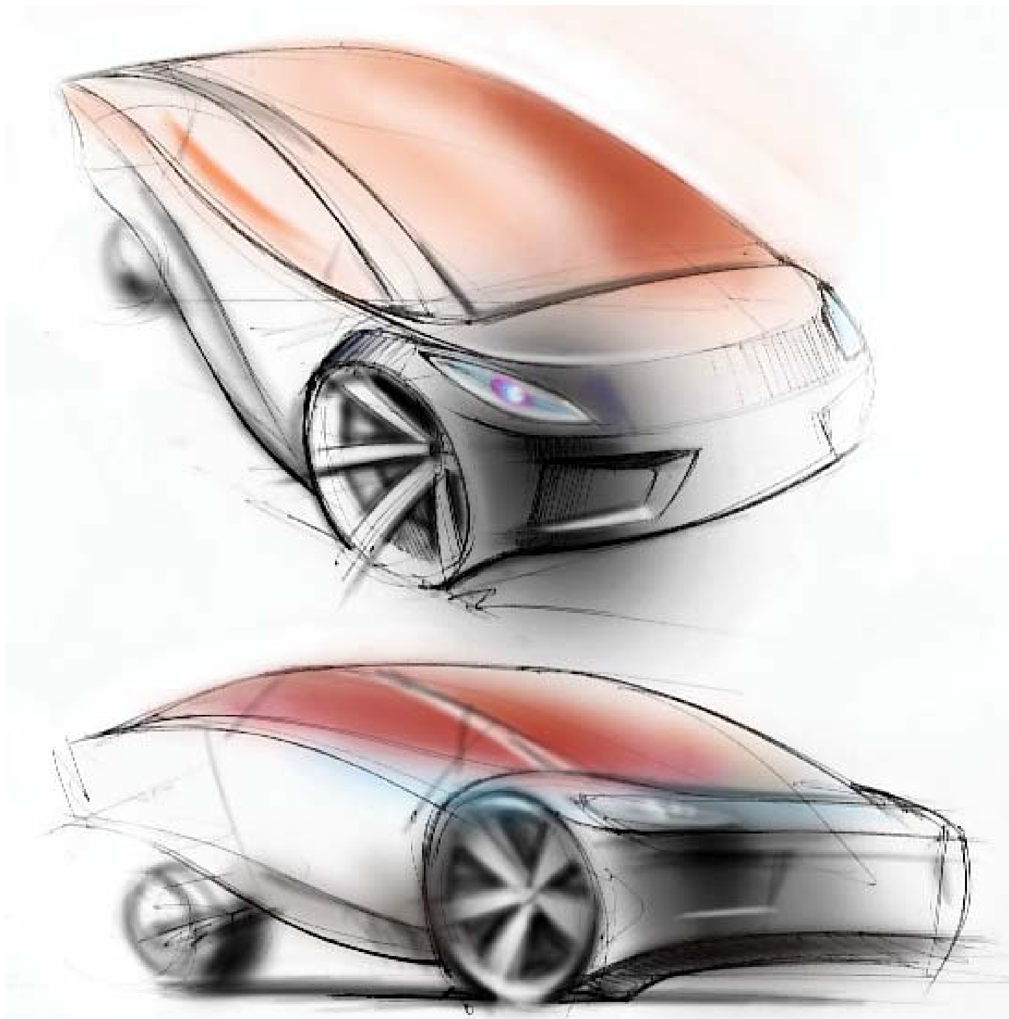

Figure 30. Development sketches of 3-wheeled vehicle with rear sphere.

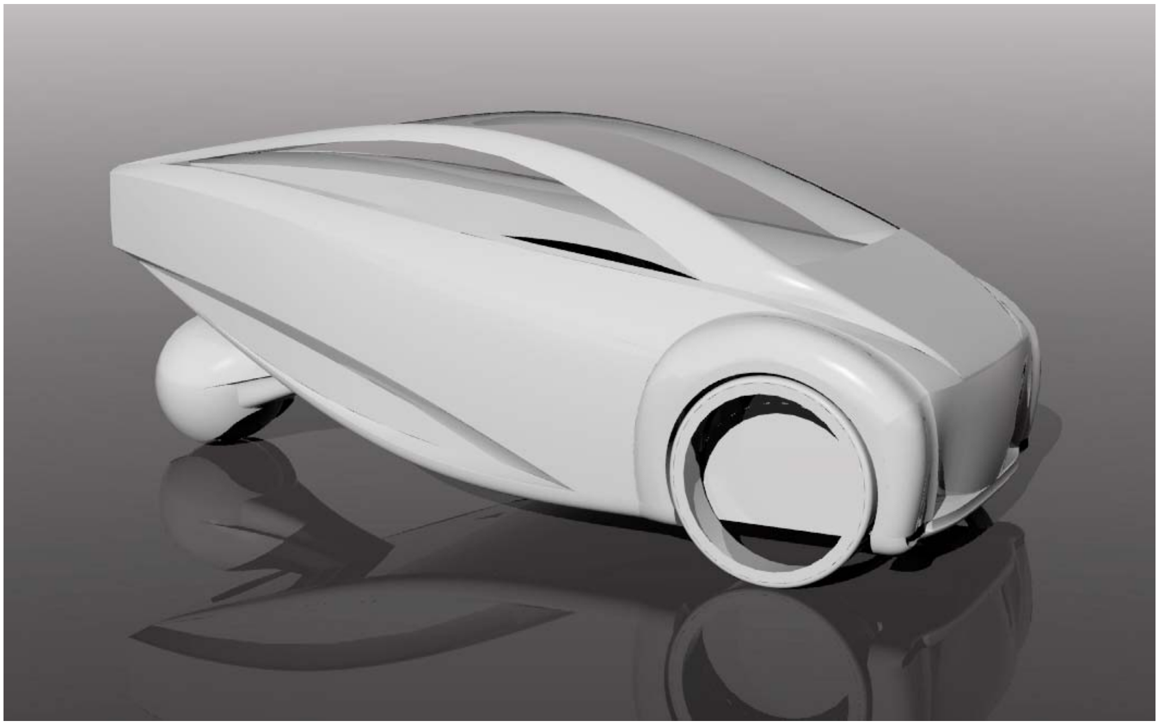

Figure 31. Model-in-white of final concept.

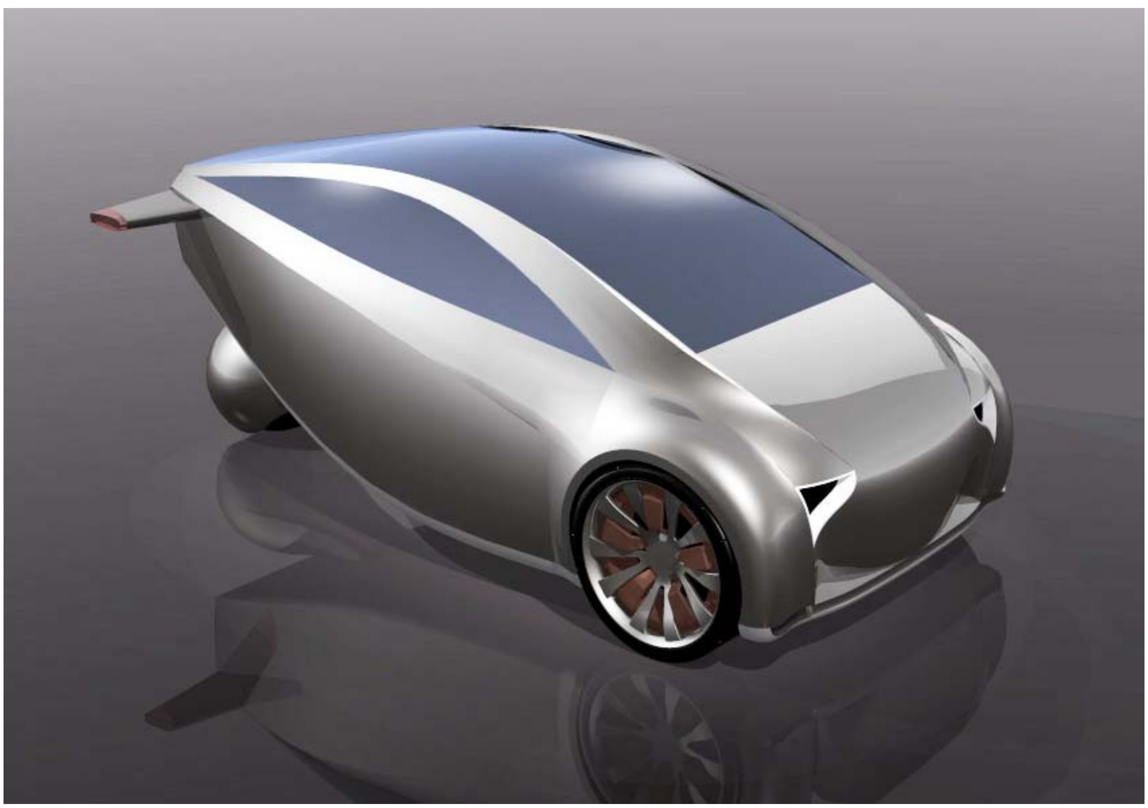

Figure 32. Final vehicle concept render.

Appendix C

Following are images of the Nissan branded version of the thesis car. Styling was modified to capture elements of Nissan cues, such as the broadly chamfered surfaces.

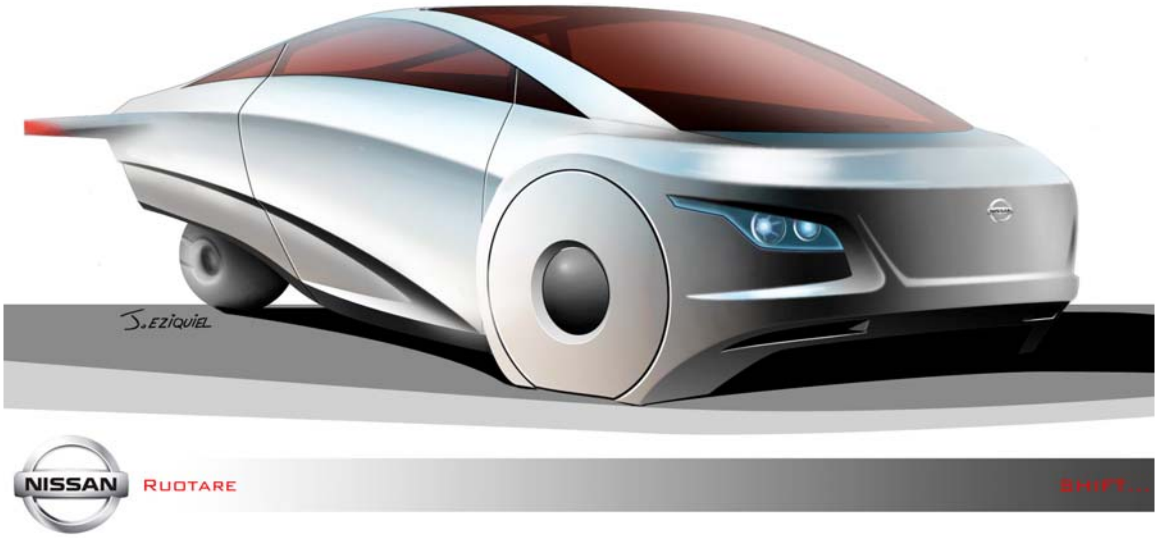

Figure 33. Nissan “Ruotare” concept sketch.

Figure 34. Nissan “Ruotare” concept sketch.

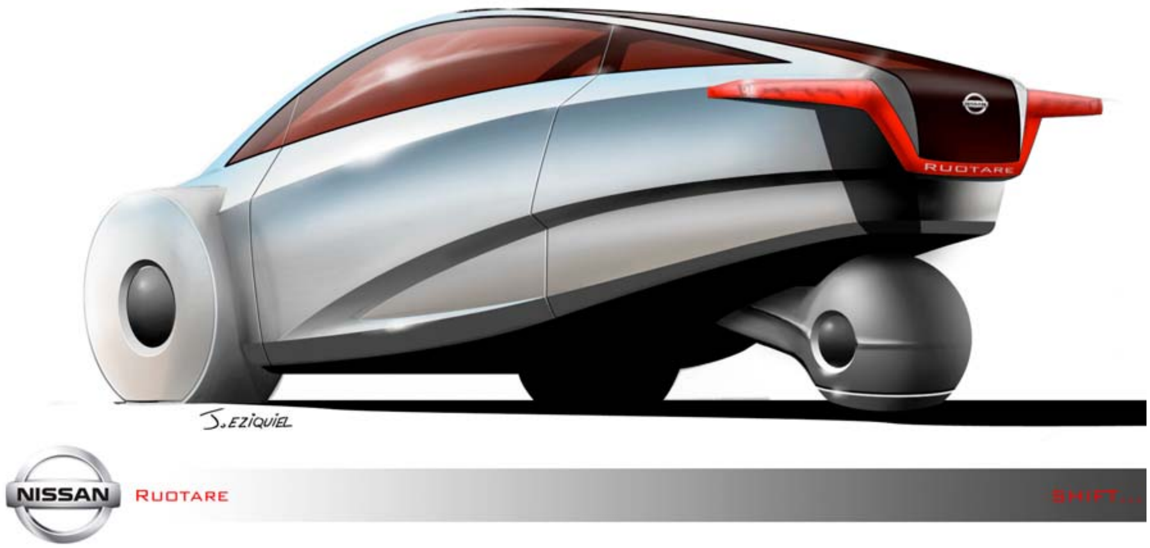

Figure 35. Nissan “Ruotare” concept sketch.

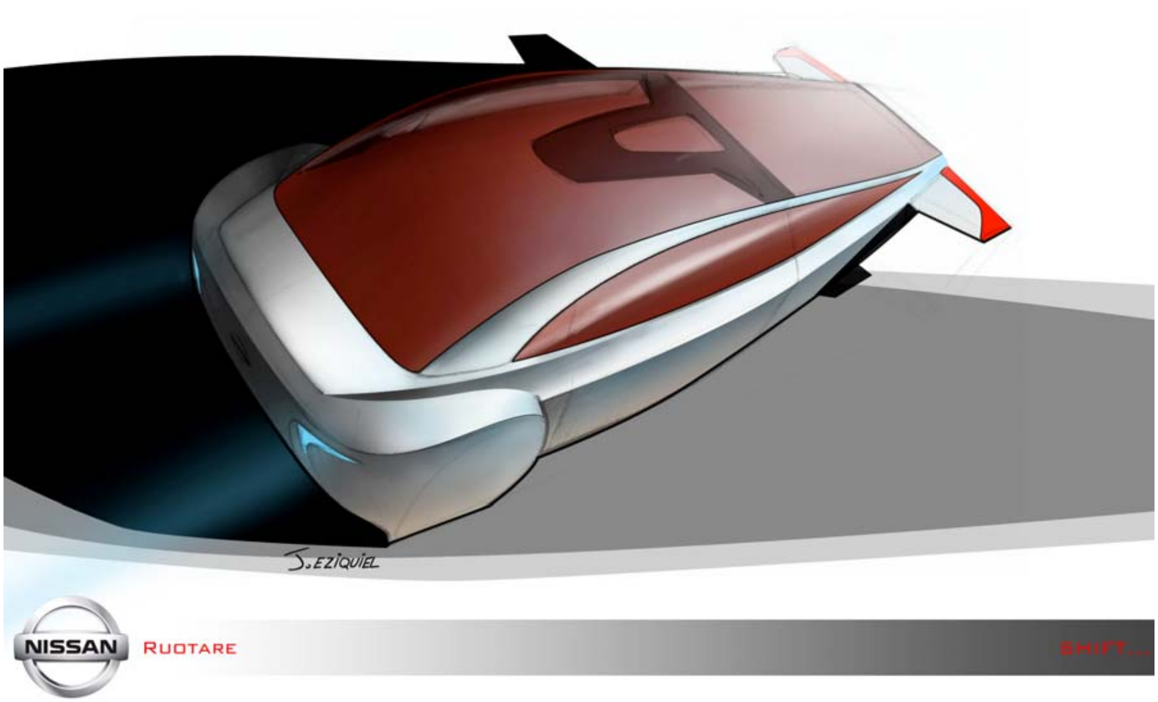

Figure 36. Nissan “Ruotare” concept sketch.

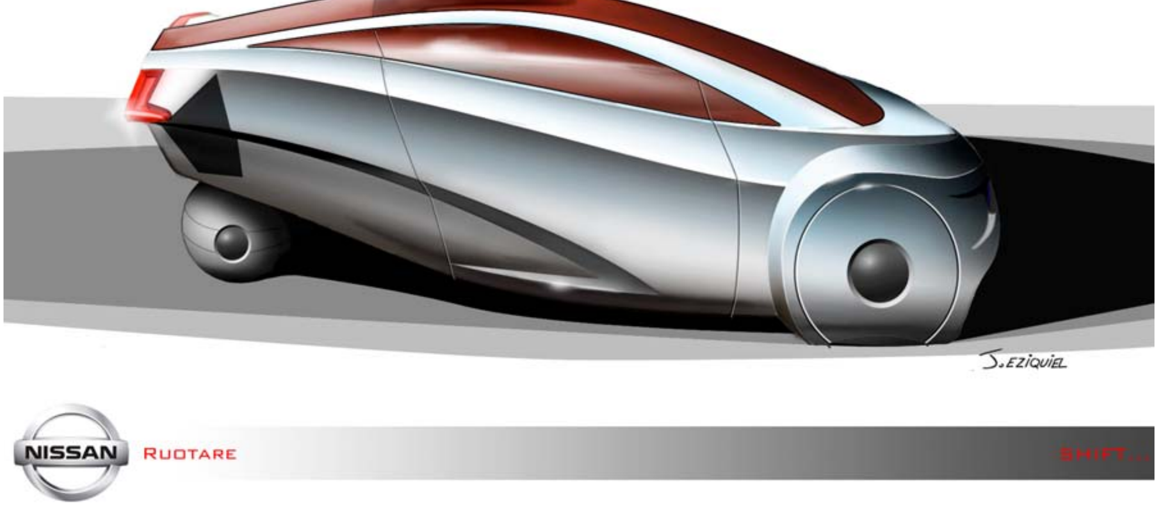

Figure 37. Nissan “Ruotare” concept sketch.

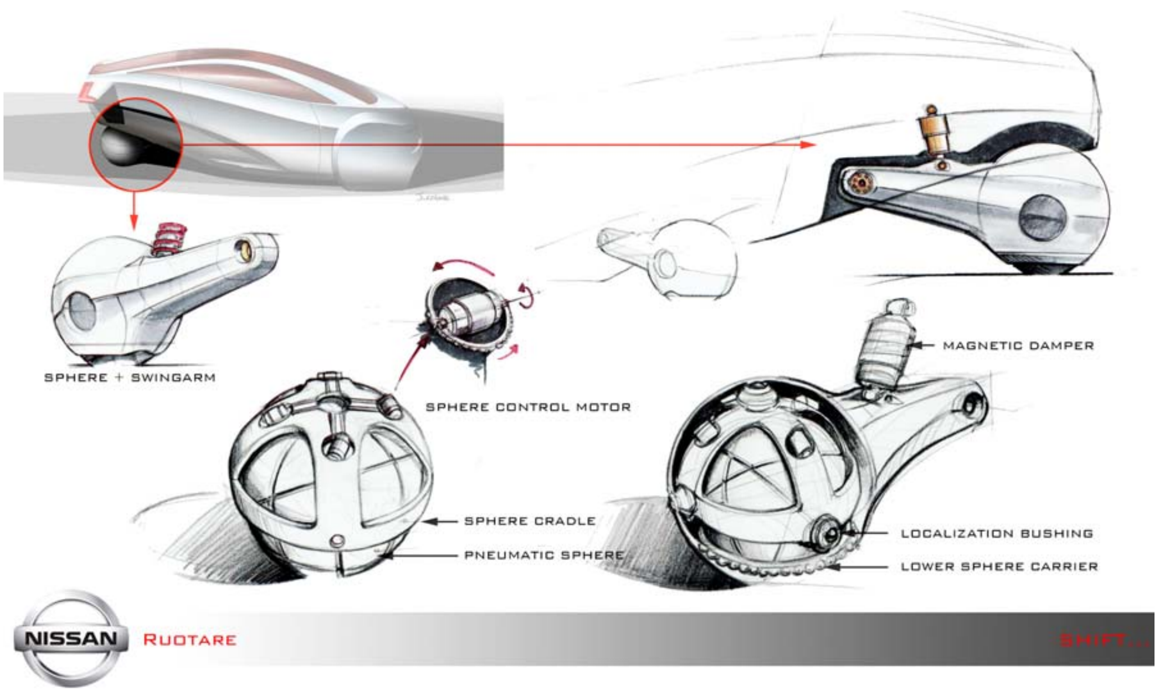

Figure 38. Nissan “Ruotare” concept sketch – sphere details.

Endnotes

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