(780 -- 917)

Proceedings of the 3rd (2011) CUTSE International Conference
Miri, Sarawak, Malaysia, 8-9 Nov, 2011

Model-T2 – Development of a low-cost sustainable vehicle

Collaboration Models in Concept Car Design

B.F. Rolfe; S. Hanafin; T.I. de Souza
School of Engineering, School of Architecture,
Centre for Material and Fibre Innovation
Deakin University, Geelong, Australia
{brolfe, sjmh, tdesouza}@deakin.edu.au

S. Datta
School of Built Environment
Curtin University of Technology
Perth, Australia
Sambit.Datta@curtin.edu.au

Abstract— **One of the largest problems facing the world today is the rise of Indian and Chinese car owners, and their lack of access to low cost sustainable vehicles. China and India have very low vehicle ownership per capita, however, this is quickly changing. Both their Governments are heavily investing in sustainable vehicle technologies to reduce green house gas emissions, and reduce each countries dependency on oil. This paper will outline a new sustainable vehicle that can compete with the low cost vehicles currently available. This novel concept was the inspiration from a cross-functional team comprising engineers and designers working on a low-cost sustainable concept car project, the Model T^2. The main features of this concept are: world first $7000 sustainable vehicle, an incredible light weight structure, and a novel steering mechanism for maximum maneuverability.**

Keywords- low-cost sustainable concept light weight; integrated simplicity; car design; design collaboration; teamwork

I. INTRODUCTION

Peak Oil production has been predicted over the past 50 years to occur sometime early in the 21st Century [1]. After 2020 the world's supply of oil will decrease. Demand for oil, however, in the short term will only increase. While in the Western nations there is very high vehicle ownership per capita, there are low (but quickly rising) ownership rates in India, China, and South East Asia. Due to the limits of oil production, both India and China has embarked on projects to develop electric vehicles to reduce the dependence on oil.

The major problem in regard to electric vehicles is the current cost of the batteries, which pushes these sustainable vehicles out of a price class that can compete with the current popular low-cost petrol based cars (Tata Nano, Maruti 800, Chery QQ). The other consideration for sustainable vehicle design is that South East Asia (including India and China) have a huge emerging middle class that are eager for vehicles.

103 years ago Henry Ford first launched the Model-T, one of the most successful cars in history. The dominance was such that at one stage in the 1920's, every second vehicle produced in the world was a Model-T. To celebrate the centenary of such a revolution in the automotive industry, Ford Global Technologies invited 5 carefully selected Universities around the world to design "the Model-T for the 21st Century". The key criteria of the challenge included: Simplicity, Compelling, Practical, Innovatively Sustainable, and the Non-traditional consumer. Deakin University's submission, "Model T^2", responded to the challenge by creating a zero emission concept car to be retailed for under USD$7000 (Figure 1.). A university-wide design research team comprising staff, researchers and students drawn from multiple disciplines from across the university (Engineering, Architecture, Intelligent systems, Material Sciences) with support from Ford Australia was formed. The design research team comprised a project steering committee and a number of cross-functional design teams working over a period of 16 weeks. The team, inspired by Henry Ford's original vision, embraced simplicity in the manufacturing of components and assemblies, combine component functionality into single systems and introduced advanced materials into the design. The result of the collaboration was a prototype tri-wheel vehicle, driven by compressed air high torque hub mounted motors in the two front wheels complemented by natural gas, steering by differential wheel speeds and use of advanced materials. This paper will describe some of the features that make it a low cost sustainable vehicle, and where this has led us towards the future.

Figure 1. Completed full scale mock-up model.

II. TEAM COLLABORATION IN MODEL-T^2

A. Team Formation

To meet the challenge two teams were established, a Project Steering Team and a Cross-discipline Design Team with technical stream leaders. Additional cross-disciplinary teams were developed by inviting participation from the many Faculties across Deakin University. This included: Architecture and Building, Engineering, Business and Law, Public Relations, the Centre for Intelligent Systems, and the Centre for Material and Fibre Innovation. The project also received external support, advice and feedback from Ford Australia.

The Project Steering Team was responsible for the overall coordination of the project including the budget marketing and promotion, provision of resources and for the successful and timely completion of the project. The Design Team was the coordinating group for all the key design tasks from styling, structures, power train, interior, electrics, and the human-machine interface.

B. Planning and information gathering

Design targets were clarified through a brainstorming session with participants from all over the Asia/Pacific region and highlighted some important key features for inclusion in the design, these included: city driving, flexibility in use, agility, space saving, need for low emissions, and easy to park.

The target market for the Model T^2 concept car is the growing cities of China and India. Market research was undertaken with city drivers in India through the use of surveys and interviews, and this provided anecdotal advice on requirements. The person's interview ranged from university students and young professionals to family bread winners and home makers. Similar advice was received from colleagues and associates who had grown up in China. Utilizing the survey data and the Design Team's intuition about what a non-traditional consumer may want, a set of consumer needs was generated.

A brainstorming session was also undertaken within the University and included participants from different Faculties. This brainstorming session focused on two specific areas; Overall Project Concepts and Sub-system Breakdown. Within these two areas different topics were consider. In Overall Project Concepts: consumer needs, revolutionizing the automotive industry, vehicle concepts / platforms / coolness. In Sub-system Breakdown: body / structure, powertrain, vehicle dynamics, interior/human interface.

C. Benchmarking and Requirements

Once the consumer needs were established, measures or metrics were determined so that the developed concepts could be assessed or ranked as well as ranked against other competitors. A benchmarking exercise was undertaken to determine how the competitors' cars compared against the metrics. This included; Smart Car – 2008, Tata Nano, Hyundai i10 – 2008, Toyota Yaris – 2008, Toyota IQ – 2009, Mitsubishi i – 2005, Chevrolet Spark, Chery QQ3, Maruti 800 Duo, Daihatsu Trevis.

Given the needs for a small, nimble and agile vehicle, well suited to cities, this prompted the decision for a three-wheel vehicle platform. Three wheel vehicles are currently becoming more popular throughout the world and are quite prominent in many Asian based countries. Often termed a tri-car or cycle-car due to its commonalities between a car and a motorcycle, have the scope to be extremely light weight, fuel efficient and yet very versatile for many urban or city residents. In many countries three wheelers come under motorcycle legislation rather than passenger car legislation. This platform lends itself to the Model T^2 design philosophy of simplicity and total integration, whilst allow for excellent maneuverability (Figure 2.).

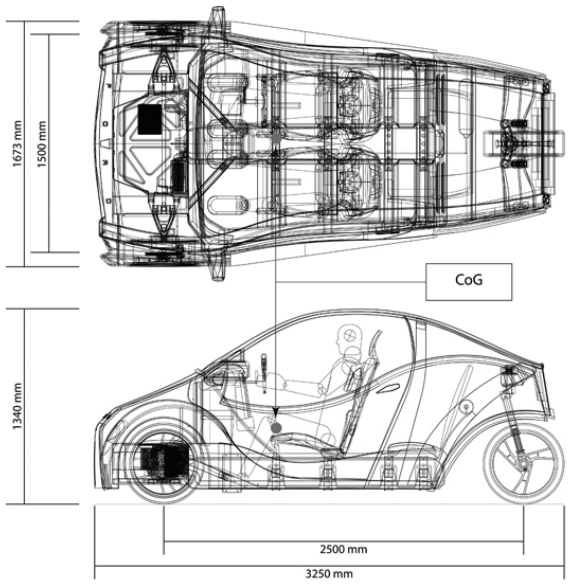

Figure 2. Model T^2 vehicle dimensions.

III. VEHICLE DYNAMICS

Simplicity, integration and lightweight were the functional design targets of the vehicle dynamics system of the *Model T*^{2}. By ensuring components served multiple purposes, through design integration, aided in reducing cost and weight, resulting in a simple but effective solution. Given the needs for a small, nimble and agile vehicle, well suited to bustling cities of today and the future, has prompted the decision for a three-wheel vehicle platform. Two direct drive hub motors allowed for the implementation of a simple speed differential steering system. By simply and precisely controlling the speed of each wheels hub motor allows the vehicle to steer; this combined with a trailing single rear wheel allows the Model T^2 to turn on the spot, making it easy to navigate through congested city streets and into tight parking spaces with ease. At higher speeds to ensure the vehicle is stable, the rear wheel is actively damped by a rotary steering damper.

Proceedings of the 3rd (2011) CUTSE International Conference
Miri, Sarawak, Malaysia, 8-9 Nov, 2011

A. Roll-over stability

A major compromise of the three wheel vehicle platform is its stability in roll-over. A simple approach has been taken to model the Model T^2 margin of safety against rollover, by constructing a base cone using the Center of Gravity (CoG) and its location within the vehicle envelopes wheelbase and track. By projecting the maximum turn force resultant allows the assessment of the rollover threshold as indicated by Figure 3.

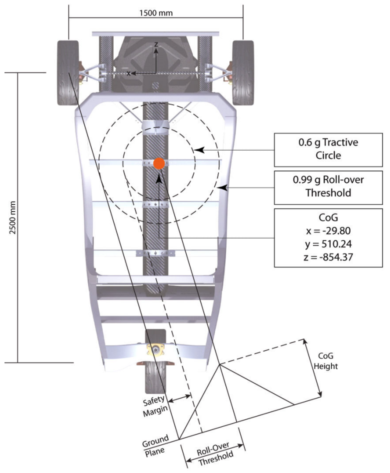

Figure 3. Rollover Kinematics for the Model T2.

Figure 3. illustrates a rollover threshold of 0.99g for the Model T^2. Assuming a tractive circle of 0.6g, which is indicative of grip levels for a small passenger vehicle, allows for a 39% safety margin. This means the vehicles tyres will slip, before the rollover threshold is reached, ensuring vehicle stability. TABLE I. displays some comparative rollover thresholds for other four wheel vehicle types, indicating the Model T^2 exhibits suitable stability.

TABLE I. COMPARISON OF ROLLOVER THRESHOLD FOR MODEL T2 AND OTHER TYPICAL VEHICLE TYPES (WWW.RQRILEY.COM).

Vehicle Type	**Rollover Threshold (lateral g-load)**
Sports Car	1.25
Luxury Car	1.25
Compact Car	1.09
Model T^2	***0.99***
Pick-up Truck	0.93
Passenger Van	0.81
Medium Truck	0.59
Heavy Truck	0.41

IV. POWERTRAIN

The selection of powertrain alternatives was completed using several criteria (packaging, sustainability, weight, cost, and power). As with the rest of the car the key themes for the choice of the powertrain were efficiency, integration, simplicity, cost and weight. Current vehicle powertrain solutions are inefficient, heavy and complex. Components like gearboxes, differentials and reciprocating engines all have significant parasitic and rotational losses that greatly reduce the overall efficiency of the vehicle.

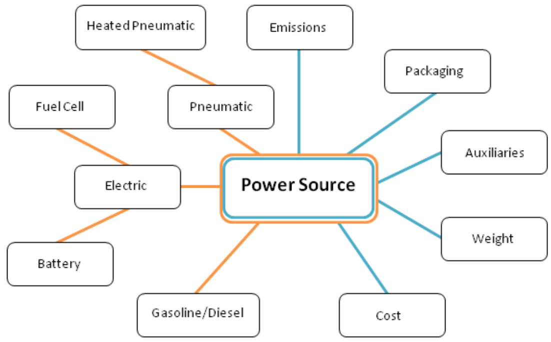

Figure 4. Engine selection criteria (blue) and possibilities (orange).

The Model T^2 incorporates two rotary compressed air hub motors (Di Pietro air motors) powered by heated air. This means that complex and expensive components like the gearbox, differentials and drive shafts are no longer required. The fuel storage, in this case air, is located down the centre of the car and forms a backbone to the chassis and body structure.

The Di Pietro air motor from EngineAir is based on a rotary piston. It uses a simple cylindrical rotary piston which rolls, with minimal friction, inside the cylindrical stator. The space between stator and rotor is divided into a series of expansion chambers, where the air is injected. This drives the piston in a rotary motion over a thing cushion of air. Timing and duration of the air inlet and exhaust is governed by a slotted timer which is mounted on the output shaft and rotates with the same speed as the motor. Variation of performance parameters of the motor is easily achieved by varying the time during which the air is allowed to enter the chamber. Motor speed and torque are simply controlled by throttling the amount or pressure of air into the motor. The Di Pietro motor gives instant torque at zero RPM and can be precisely controlled to give soft start and acceleration control. Their small size, lightweight and compactness aids in the integration of all components in the car. Not only do they serve as device to create motion, but as critical suspension components, with one located in each front wheel.

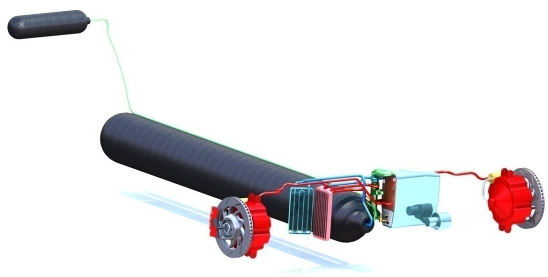

Figure 5. Overview of powertrain components and location.

Proceedings of the 3rd (2011) CUTSE International Conference
Miri, Sarawak, Malaysia, 8-9 Nov, 2011

In order to get greater efficiency/range out of the air stored in the air cylinder, the air must be heated. This is done by passing the air through a heat exchanger heated by a small natural gas burner. The burner and heat exchanger are located in the front of the vehicle whereas the Compressed Natural Gas (CNG) cylinder is located at the rear of the vehicle. Figure 5. shows the powertrain solution for the Model T^2 concept. The Model T^2 can run entirely on compressed air with a reduced range (approximately 60km to 80km), thus making it a zero emission vehicle.

V. LIGHTWEIGHT BODY DESIGN

The Model T^2 vehicle and body structure were designed with careful consideration of several key attributes, which were essential to ensure that our performance and design targets were met. These attributes were:

- Occupant safety;
- Manufacturability;
- Cost;
- Weight;
- Structural rigidity;
- Modularity;
- Packaging;
- Sustainability.

Our design philosophy of "integrated simplicity" continued strongly into the vehicle body and structure, such that the often conflicting design requirements of each of the above design attributes could be met. The use of new and/or non-traditional materials and manufacturing processes were key enablers for the successful design.

A. Structural Concept

The design of the Model T^2 vehicle body and structure concept was focused around distinct upper and lower vehicle assemblies (Figure 6.). The lower assembly can be considered essentially as a rolling chassis, providing a large portion of the vehicle's strength, stiffness and energy absorption capabilities, whilst the light-weight upper assembly forms most of the exterior components of the vehicle.

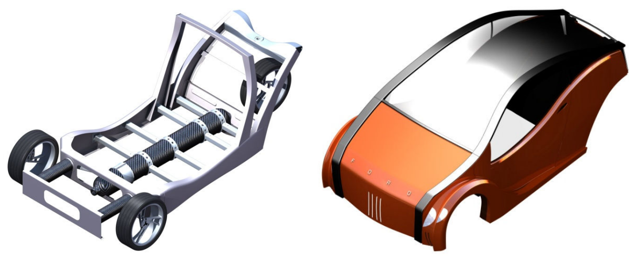

Figure 6. Lower and upper vehicle body assemblies

There are significant advantages associated with this two-assembly concept, as compared to the traditional monocoque approach [2]. Firstly, the fact that the structural members are independent of the "stylized" exterior components allows the use of much simpler and more structurally efficient components, thus providing large weight savings. The simpler shapes also allow the employment of lower cost manufacturing processes and higher strength materials. These combining factors result in a significant reduction in the overall cost and weight of the vehicle, whilst still maintaining excellent structural performance.

Another advantage of the separate rolling chassis is the degree of modularity and flexibility of exterior shape that it provides. Modularity to enhance customization of vehicles is has been seen as one of the major drivers for future body structures [3]. Most of the exterior panels can be changed with very low new tooling costs, and without affecting the structural integrity of the vehicle, thus allowing the vehicle manufacturer to quickly respond to consumer demand. There are similar benefits in terms of repairability, where exterior panels can be easily replaced, in the case of a minor vehicle accident.

Traditionally, automotive structural components are manufactured using the stamping process, which requires the sheet steel to have significant amount of ductility, thus limiting the strength of the material [4]. By using simpler shaped components, which have constant or near-constant sections throughout their length, the roll forming process can be adopted. Roll forming requires significantly less ductility; therefore much higher strength grades can be employed.

The automotive industry has been using roll forming for many years in order to manufacture long straight sections, due the large cost advantages. Recent advances in roll forming technology [5] have now made it possible to manufacture curved sections or sections with varying profiles – such process are commonly referred to as 3D or flexible roll forming. Therefore, the flexible roll forming process offers the ability to produce more complex shapes, very efficiently and at high production rates.

Deakin University has been working on a number of vehicle concepts based on flexible roll forming. At the International Symposium on Automotive Steels (ISAS'2009) [6], Prof Duncan and Deakin University presented a new concept of a fully roll formed vehicle, to propose an extremely cheap car concept (Figure 7. and Figure 8.).

Figure 7. Complete roll formed vehicle.

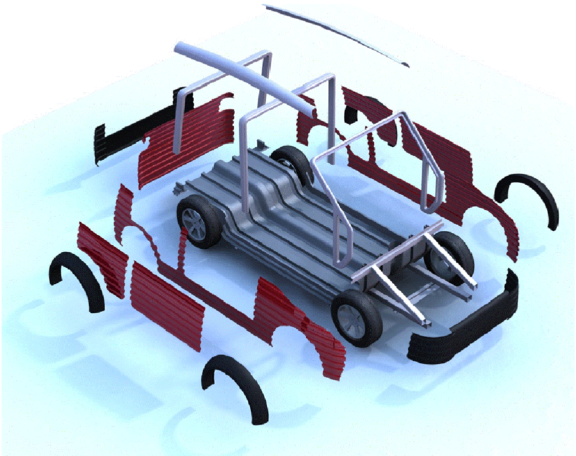

Figure 8. Exploded view of the roll formed vehicle.

Deakin University is also part of a research consortium (AutoCRC, Deakin, RMIT, Swinburne University of Technology, ANU, VPAC) to generate a visionary modular light weight body structure, in part inspired by the Model-T^2 concept (Figure 9.).

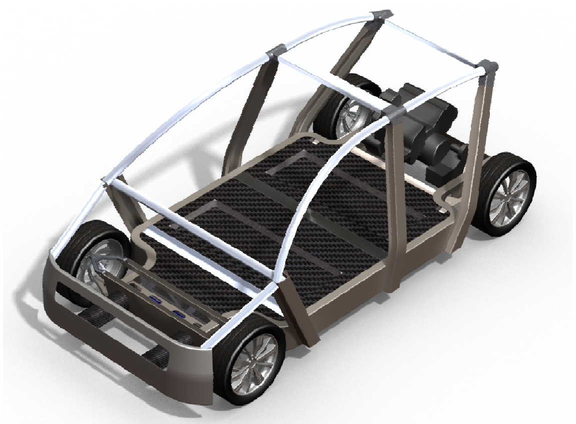

Figure 9. Early version of the visionary Light-weight Modular Vehicle Platform body structure (LMVP).

VI. SUMMARY

This paper outlines the Model-T^2 design for a cheap zero-emission car for the 21st Century. The Model-T2 is a zero emission car with reduced range when running on compressed air alone. Our design philosophy was influenced by Henry Ford's original thinking, which was new and different, and embraced simplicity and functionality in design. Henry Ford integrated his knowledge of materials, design and manufacturing to: combine functions of components into single systems; simplify the manufacturing of components and assemblies; and introduce advanced materials to the design. This approach has influenced our development of new vehicle concepts and body structures.

ACKNOWLEDGMENT

We gratefully acknowledge the support of the following people who contributed to the Model-T^2 project. The Steering Committee of Bernard Rolfe, Noel Miller, Chee Jin Yap, Tim de Souza, Stuart Hanafin, Sophie Torrens, Tim Hilditch, Ian Burston, and Emeritus Prof. Ian Duncan . The design team members, Tim de Souza, Greg Pitts, Stuart Hanafin, Steve Agius, Ben Adamson, Michael Pereira, Tim Black, Chris Hurren. We must also acknowledge the gracious financial support of Ford Global Technologies for the project, and for the information provided by EngineAir on the Di Pietro motor.

REFERENCES

[1] Campbell C.J., "Myth of spare capacity setting the stage for another oil shock".Oil & Gas Journal, vol. 98, pp. 20-21, 2000.

[2] Fuganti, A., "Future Evolution of Automotive Vehicle Structure", in Proceedings of the Automotive Circle International conference - Fascination Automobile Modularization. Bad Nauheim, Germany, 2006.

[3] Pandremenos, J., et al., "Modularity Concepts for the Automotive Industry: A Critical Review". CIRP Journal of Manufacturing Science and Technology, 2009. **1**(3): p. 148-152, 2009.

[4] Stehlin, M. "Super Light Car - Sustainable Production Technologies for CO2 Emission Reduced Lightweight Car Concepts (SLC)". in Transport Research Arena. Ljubljana, Slovenia, 2008.

[5] Sedlmaier, A, Hennig, R, "Improving the Sustainability of Flexible Roll Forming with Curvature Optimized 3D-Profiles", International Deep Drawing Research Group Conference, Bilbao Spain, 2011.

[6] Duncan, J.L, Developments in Metallurgy and Application of High Strength Sheet Steels, International Symposium on Automobile Steel (ISAS'09), 2009