International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-3, September 2019

Shape Optimization with Computer Fluid Dynamic (CFD) Analysis of Micro Electric Vehicle

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Abstract: *Car drag reduction activities are parts of exterior body improvement which related to energy consumption, wind noise and stability of overall vehicle. Micro Electric Vehicle (MEV) has emerged as one of human mobility that aligned with the concept of low energy consumption. The concept has gained popularity due to its simplicity in design and manufacturing capability which in overall, leads to less energy consumption for both vehicle owner and manufacturer. The aim of this work is to design an MEV where the passenger's anthropometry of 95th percentile male and 5th percentile female have been considered as a main factor. 3D data of MEV has been developed based on scaled down conceptual design from clay model. Computer Fluid Dynamic (CFD) analysis were used on actual size of MEV to determine the effect of the vehicle height. Maximum speed of 30m/s has been introduced in the analysis. The speed is a simulation from real world condition of mobility which will be the limit speed of the vehicle.* ***As a result the 128mm increase in streamline height has significant impact on the drag force where the drag coefficient increase approximately 31% to the initial height. As a conclusion CFD approach can be used to successfully determine an optimal height of MEV based on streamline design. The finding significantly assist in future improvement of streamline design of the MEV.***

Index Terms: ***Automotive Design, Clay Modelling, CFD Analysis, Drag Coefficient, Micro Electric Vehicle.***

I. INTRODUCTION

Micro Electric Vehicles (MEV) is small 2 passengers car, drive by electric motor has a potential to contribute to greener environment. The size of the vehicle is smaller compare to conventional Electric Vehicle (EV) thus reduce the energy consumption significantly. This paper is a continuation of previous research consist of various engineering activities such as conceptual design, clay modelling process, 3D scanning, surface creation, 3D development and CFD analysis and shape improvement.

In determining the overall exterior shape of micro electrical vehicles (MEV), the imagination is interpreted through sketches and recognize as conceptual design. Sketches is a freeform drawing with little consideration on engineering aspect. What normally appear as conceptual design is none other than visual of vehicle with aesthetic value and lack of engineering information. The more engineering consideration during early stage will decrease the engineering changes during development. It is normal for most of styling department to consider airflow streamline when developing the conceptual design of the vehicle. Further development of automotive concept design often leads to development of 3 Dimensional (3D) concept such as clay model. The involvement of clay model in vehicle development always include the creativity of industrial designer and considered to be crucial since the aesthetic value of the design will influence the customer's buying decision. After the agreement on the suitable styling, the concept design need to be translated into 3D data and it will be improved with engineering information to ensure the vehicle is suitable for manufacturing standard, safety and regulation requirements are all meet. There could be various types of tests depending on the Original Equipment Manufacturer (OEM) requirement [1].

This is the stage where engineering and styling capability will integrate. The initial concept of the design will have to consider the large percentage of human percentile to make the vehicle relevant to large percentage of human kind. The changes made to the vehicle after considering human packaging constraint will affect the vehicle height and leads to air flow turbulence of the vehicle. The development of concept design and initial analysis engineering capability towards the concept design has to run concurrently in order to expedite the development process. Initially, the flow analysis will be performed on the 3D data of the concept design as part of earliest engineering feedback. Technical specification is also needed to determine the velocity of vehicle in order to simulate the wind flow which normally can be retrieved from the vehicle profile, determined by the feasibility study during planning stage.

Manuscript published on 30 September 2019
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II. MICRO ELECTRIC VEHICLE DEVELOPEMENT

Micro electric vehicle is a one or two-seater vehicle powered by battery with an electric propulsion power rating of 4-10 KWh [2]. In developing the concept design of the vehicle, we start the project with sketching. With consideration of wind streamline, the smooth curvature of exterior design were taken into consideration. In order to get better understanding on the vehicle to be developed, a clay model of the vehicle has been created. The clay with scale 1:10 of the real vehicle will provide a better information with 3D visual view. apart from that, this activity is important to assist in developing 3D CAD data of the whole concept. The clay model will be scanned and converted into surface and solid in CAD for various application. 3D scanning has the ability to provide a reliable measurement data in shorter time and has been reliable even for the application of quality inspection [3]. The accuracy of the measurement will be an advantage in developing CAD surface as closest as the clay model. In CAD condition, the data will be transform into 1:1 scale to get the closest condition as actual vehicle on the road. Figure 1 show the process of 3D scanning using photogrammetry method.

Figure 1 : Clay model of the concept design is scan using photogrammetry method.

The 3D CAD data is then underwent a Computer Fluid Dynamic analysis as this is the fastest analysis and provide a useful engineering information to the project. Concurrently, analysis of human packaging was also conducted on the 3D CAD data. In this activity, 95th percentile of European male is used to represent the maximum critical value of the vehicle size. Similarly, 5th percentile of European female is used to determine the critical minimum value of the same vehicles. The height of the initial vehicle in 3D CAD data is approximately 1,272mm. CFD analysis has been done on the first concept with result of the CFD can be found in Discussion chapter. Figure 2 show the side view of the initial vehicle with height of 1,272mm

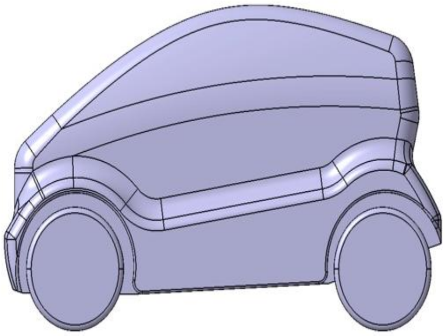

Figure 2 : 3D CAD data of the initial concept.

The most significant aspect to be considered in vehicle development is the optimum vehicle dimension with relate to human sitting position and interaction with surrounding. With refer to 5th percentile of European female size positioned in the MEV, the vehicle show an ample packaging towards roof streamline and passenger's head clearance. However, with 95th percentile of European male in the same position, the passenger's head is protruding from the roof streamline. Figure 3 show both conditions of male and female positioned in the vehicle respectively. This issue is predictable as clay modelling process only concern on aesthetic value of the car and less consideration on human packaging. It is obvious from Figure 3 that a new roof streamline need to be defined. Since the 3D data of MEV is available, next modification will largely be done in CAD condition.

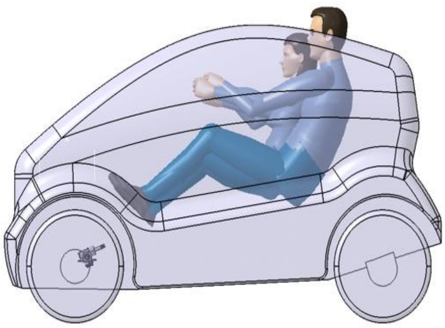

Figure 3 : Human packaging in sitting position.

III. STREAMLINE IMPROVEMENT.

Now that we have identified the area that require improvement, we then require a specific height to be incorporated in the 3D conceptual design. Detail measurement taken from CAD data has shown a new height of 128mm from original streamline is required. The new height has taken into account the head clearance for both female and male condition. Although the height increase is consider to be minor but the it change the whole look of the MEV. Figure 4 show the effect of the changes onto overall appearance of the MEV. The improvement in streamline has result to overall height of 1,400mm.

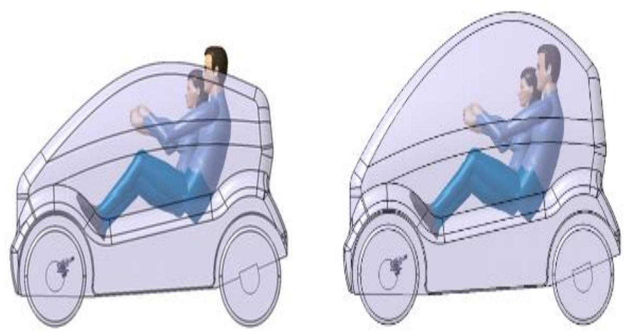

Figure 4 : Streamline improvement on the right picture.

IV. COMPUTER FLUID DYNAMIC

Based on the research study of the Micro Electric Vehicle design, there are several research that used CFD in performing analysis such as battery efficiency [4], headlamp condensation [5], radial fan for motor cooling [6] and many more[4]–[10]. Computational Fluid Dynamics (CFD) is an advanced type of aerodynamic analysis software that usually used to understand the relation of several parameters in case study. It enables users to study on aerodynamic of vehicle base on flow pattern around or through a vehicle. In this study, the software that we used to perform the simulation is SolidWorks Flow Simulation.

The speed applied in the CFD simulation is 30m/s. This is the limit speed as mentioned in the initial technical specification of MEV. The analysis type was selected as an exterior as the simulation will consider the effect of wind flow towards the outer shell of the CAD data. In determining the type of fluids, gases were selected and the type of gases for the simulation is air. Then, by adding velocity value towards Y negative direction due to design coordinate and the wind speed to simulate actual maximum driving condition as 30 m/s.

Two different designs were analysed in this activity. The first design is the original height as translated from clay MEV model. Then, using the same method second design was introduced as the result of human anthropometry analysis. The second analysis on improved height is to understand the effect of height increase towards drag force. What considered to be small increase in height can be significant towards drag force in total.

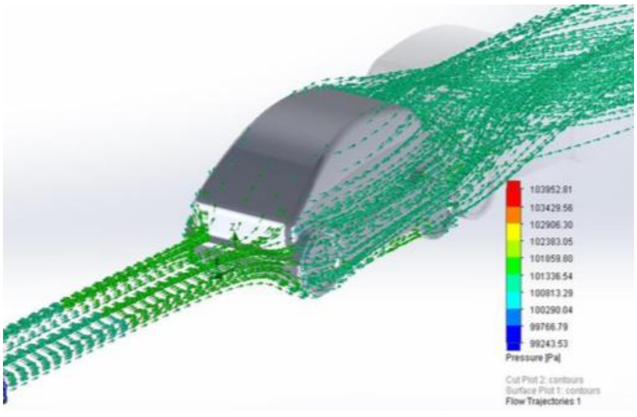

Figure 5 : Flow pattern of the MEV

The length for computational domain is set to be longer than the length of the MEV. The length from front MEV is set to be 1.5 times vehicle length and the length of computational domain at the back of MEV is 2.5 times the length of the vehicle. This is to allow the flow to be stable and optimal before hitting the MEV and also provide a sufficient distance for flow pattern at the rear. In Figure 5 the flow trajectory show a smooth flow pattern at side and top of the vehicle. It is understandable the turbulence will start to occur at the back of the vehicle as the design line show a sudden drop from roof line towards the tailgate of the vehicle. Nonetheless, the focus of this analysis will be the effect of the rooftop streamline.

In Figure 6 there are two figures showing the changes of pressure in from approximately side view. when comparing both figures, we can see the highest pressure dictated at the front area of the vehicles. This is due to the sudden impact from smooth air flow perpendicular to the vehicle surface. As the flow moving upwards, the pressure decrease slowly nearing to the roof line. With increase in vehicle height, the streamline connected to the front surfaces are also changed. This is to keep the line running smoothly from front of the vehicle towards the rear. As we can see from the pictures, the position of pressure drop also changed with the changes of streamline indicating the changes of air velocity between the two different design. The region of lowest pressure also has shrunk in the improved height condition compare to the initial height. The increase of drag force in the improved height condition can be spotted with the decreasing of pressure area and this could lead to more energy consumption in the real world condition.

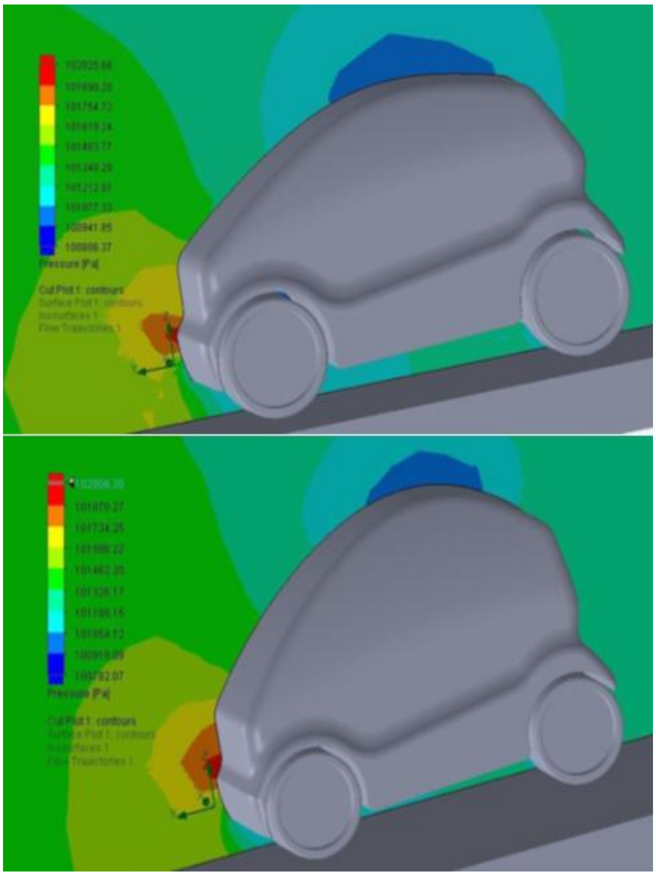

Figure 6 : Initial height (top) and improved height (bottom)

Figure 7 show the pressure mapping in isometric view of the vehicle. The pictures further support the argument on pressure changes with the increase of vehicle streamline height.

The pressure region has change with more pressure at the front area for improved height compare to the initial height. The improved height of the vehicle prevent the air flow from passing through the roof streamline. This situation has resulted to accumulation of air in front of the vehicle and thus slowing down the air velocity which result to increase in drag force at the front. Since the high pressure region has enlarge towards the windscreen area of the vehicle, this phenomena has effected the lowest pressure region as well. The air flow is slowly gaining its velocity before finally morphing with the surrounding air velocity again near to the top area. The value of drag force in stated in Table 1.

Table 1 : Drag force comparison

Description	Average (N)	Min (N)	Max (N)
Drag Force Initial Height	1787.273	1156.303	9014.084
Drag Force Improved Height	1986.012	1514.571	4934.492

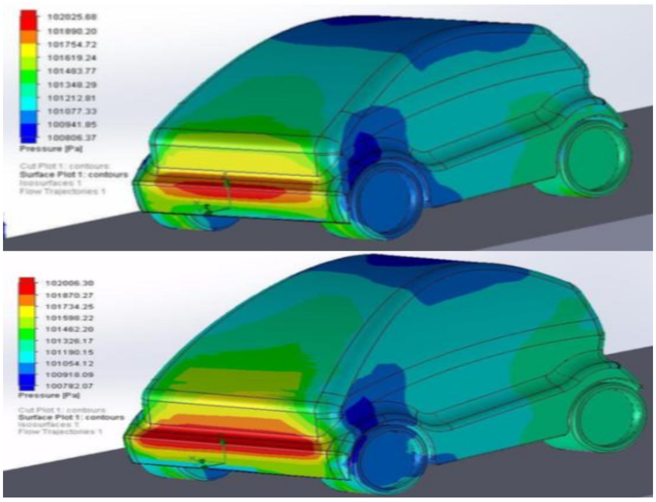

Figure 7 : Initial height (top) and improved height (bottom)

V. CONCLUSION

In most of the cases in automotive development, finding the optimum vehicle height using CFD analysis is very challenging. The overall height of vehicle is subject to human packaging which include sitting position and human percentile. Nonetheless, CFD analysis can provide an initial engineering feedback to the development of MEV and continuously to do so. In this research, a relatively small (128mm height) increase in vehicle height to provide sufficient head clearance has a significant impact on overall drag force of the car. The drag coefficient of the initial height is calculated to be 1.13 but the value change dramatically to 1.49 when analysed with improved height. This is an increment of 31% in drag coefficient. Obviously, the MEV require further improvement in streamline design to decrease the drag coefficient value which will be the objective in the next research. As a conclusion CFD approach can be used to successfully determine an optimal height of MEV based on streamline design. The finding significantly assist in future improvement of streamline design of the MEV.

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