

# Research of the Design Feasibility of a 3-Wheel Electric Vehicle with a Simplified Control System

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**Abstract:** The need for a simple, customised electric vehicle (EV) has inspired the research of the possibility to build a simple EV tailored for the specific needs of the buyer. This paper is focused on the concept of an EV with no conventional control mechanism. In this paper, a research of user needs, vehicle dynamics, vehicle aerodynamics, type of drive and batteries was carried out. EV aerodynamics characteristics were simulated by using the Computational Fluid Dynamics (CFD) software. The control system was designed in correlations with the maximal safe velocity and the radius of EV turning on a circular path. The stability of the EV, concerning the vehicle turning over and wheels slipping while driving in the curves, was the main concern of this paper. The steering wheel and brake pad were replaced with a control stick. Using the Finite Element Method (FEM) analysis, key parts of the construction were constructed.

**Keywords:** custom made EV; electric vehicle; stability; 3-wheel vehicle; vehicle building; vehicle dynamics

## 1 INTRODUCTION

For this research, an investor respectively the future user, specified that with the vehicle, he wants to satisfy 80% of his annular needs for transportation. Measurements of user's daily transportation requirements were taken in the period of one year as shown in Fig. 1.

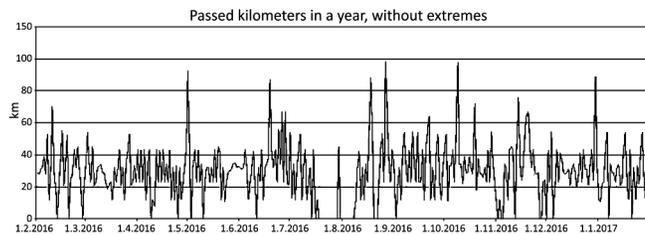


Figure 1 EV user's annular transportation requirements

It was deduced that the daily requirement of 60 km satisfies 83.3 % of user's requirements. Furthermore, it was specified that the EV should be able to transport two passengers. Taking all that into consideration and having in mind the minimization of the EV's air drag, friction and mass, the design shown in Fig. 2 was chosen.

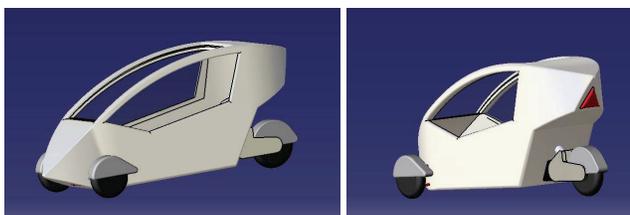


Figure 2 EV's design

## 2 CFD INVESTIGATION OF EV's AERODYNAMICS CHARACTERISTICS

In order to calculate the EV's drag coefficient  $C_d$ , CFD simulations were conducted. The inlet of the rectangular domain was positioned  $2L$  upstream of the EV profile, the

ground is  $12L$  long and is  $0.065L$  from the front wheel axis position, as discussed in [1]. The mesh size was variable, from the smallest elements near the vehicle body to the biggest further away from it, providing  $y^+$  between 30 and 90, as discussed in [2]. Turbulence was simulated by two RANS models: the realizable  $k-\epsilon$  two-layer model, and SST  $k-\omega$  model, as described in [2] and [3].

After the verification of the numerical model, using the procedure described in [4], the drag coefficient was determined to be  $C_d = 0.54$  for the chosen EV's design.

The drag force ( $F_d$ ) of the EV was calculated from the Eq. (1), and represented in Fig. 3.

$$F_d = \frac{\rho \cdot A \cdot C_d \cdot v^2}{2} \quad (1)$$

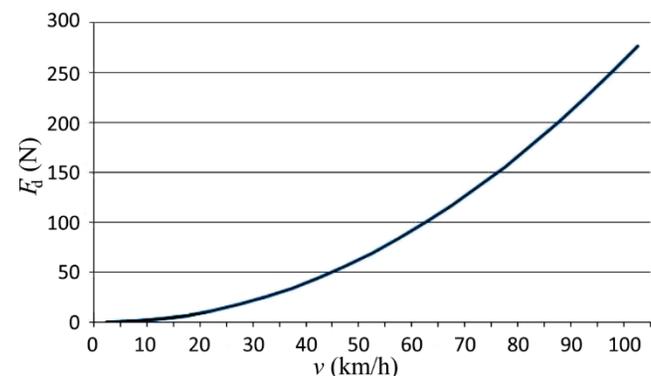


Figure 3 EV's drag force

## 3 CHOOSING ADEQUATE ELECTRIC ENGINES

To design the needed drive, the total resistance force to motion was calculated as explained in [5]. Apart from the aerodynamic drag, the rolling resistance force when traveling in a straight line and the climbing resistance force were calculated in Eq. (2) and presented in Fig. 4.

$$F_{TR} = F_d + F_{Ro} + F_{St} \quad (2)$$

In wheel electric motors of 3000 W, the nominal power output of 180 N·m torque was chosen. The chosen motors were manufactured by QS Motor [6].

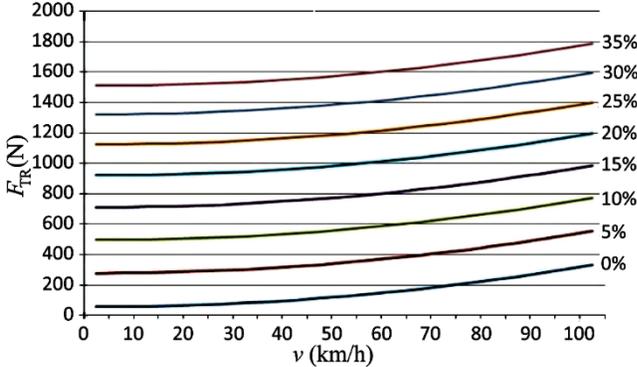


Figure 4 Total resistance to motion depending on the velocity and road inclination

#### 4 CALCULATING THE REQUIRED BATTERY CAPACITY

Voltage is determined by the chosen motors and it must be 72 V. The total motion resistance of cruising at 80 km/h on a plain road is  $F_{TR} = 234.11$  N, as shown in Fig. 4. Having wheels with a radius of  $r = 250$  mm dictates the rate per second (RPS) to be 14.15. By using Eq. (3), it was determined that the required power for the described movement is  $P = 5200.2$  W.

$$P = 2 \cdot F \cdot r \cdot n \cdot \pi \quad (3)$$

Some resistant forces were neglected in order to get real required power, and the power calculated by the Eq. (3) was multiplied by the safety factor of 1.15. This yields that the real required power per motor is  $P_m = 1993.41$  W.

From Fig. 5, which shows the QS motor characteristic, it can be determined that for them to give  $P_m$ , the total theoretical current of  $I = 96$  A is needed. When the motors individually give  $P_m$ , their efficiency is  $\eta = 89.9\%$ , hence the total current of  $I = 107$  A is actually needed.

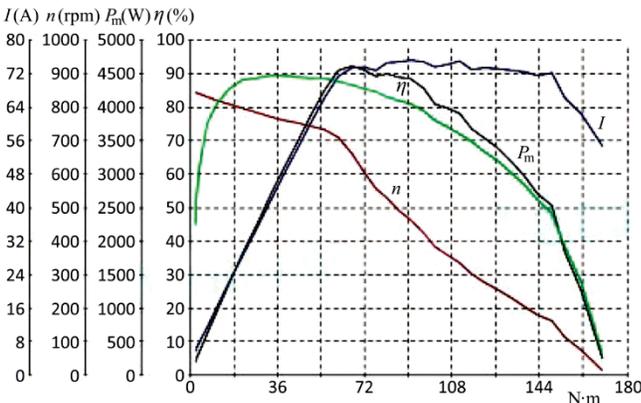


Figure 5 QS motor characteristics, [6]

As stated before, EV is then supposed to travel 60 km per day and with an average velocity of 80 km/h, which means that the EV will be used for  $t = 0.75$  h daily. By using the Eq. (4),

$$Q = I \cdot t \quad (4)$$

it is yielded that the battery capacity needs to be  $Q = 100$  Ah.

#### 5 MANOEUVRABILITY OF THE ELECTRIC VEHICLE

The majority of classic vehicles (e.g. cars) are manoeuvrable only around the vertical  $z$ -axis. This vehicle is manoeuvrable around two axes, the  $z$  and  $x$ -axis, as shown in Fig. 6.

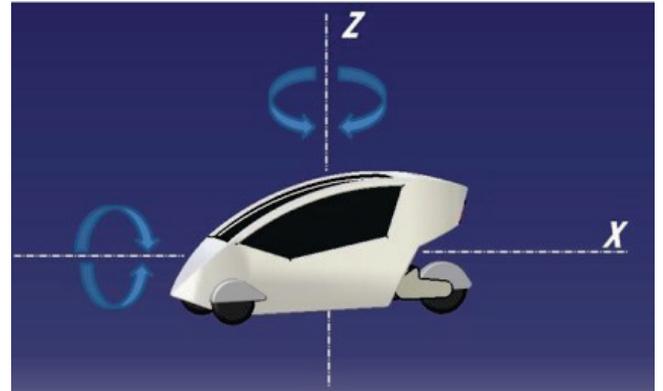


Figure 6 Manoeuvrability of the EV

The decision to make this EV manoeuvrable around two axes was derived from the requirements for a greater manoeuvrability and stability of a three wheels EV with a relatively narrow space between front wheels.

##### 5.1 Manoeuvrability around the $z$ -Axis

Turning the  $x$ -axis around is accomplished by turning the front wheels left or right. By changing its direction, the vehicle moves along the circle with the radius  $r$ . The velocity along that circle is limited because of two reasons:

- a) wheel slipping due to a bigger centrifugal ( $F_c$ ) than friction force ( $F_f$ )
- b) tilting the vehicle due to the high position of the centre of gravity.

If  $F_c \leq F_f$ , wheel slipping will not occur. By using the Eq. (5), Fig. 7, which represents the max velocity before the vehicle starts slipping depending on the turn radius, was made.

$$v_{slip} = \sqrt{\pi \cdot g \cdot r} \quad (5)$$

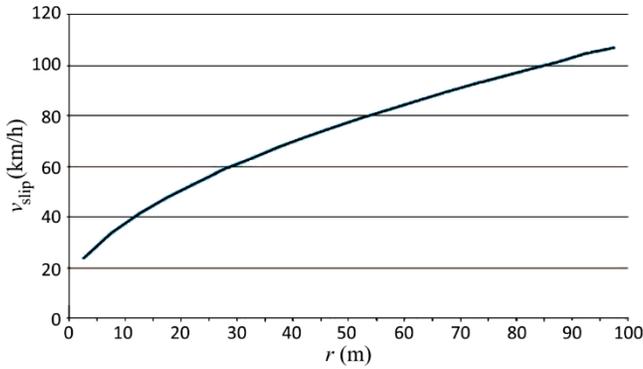


Figure 7 Maximal EV velocity before it starts to slip

### 5.2 Manoeuvrability around the x-Axis

Centrifugal force acts at the centre of gravity, when multiplied by its distance from the point A  $L_f$  (length from A to the horizontal axis from G), creates a centrifugal momentum ( $M_f$ ) which tends to tilt the vehicle over the front wheel A which is traveling on the inner circle (a wheel traveling on a smaller radius), as it is shown in Fig. 8.

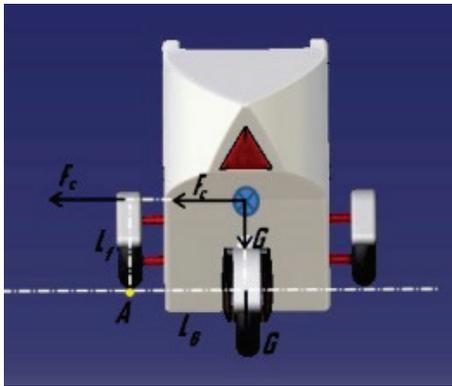


Figure 8 Forces acting on EV when turning

On the other hand, the EV weight multiplied by its distance from the point A ( $L_G$ , length from A to the vertical axis from G), creates a weight moment ( $M_G$ ) which tends to keep the vehicle stable with all wheels on the ground.

When  $M_f \leq M_G$ , the vehicle is stable without tilting over the front wheel A. Having that in mind and using the Eq. (6), the maximal EV velocity before tilting over when EV is curving was calculated, as shown in Fig. 9.

$$v_{\text{tilt}} = \sqrt{\frac{r \cdot \mu \cdot g \cdot L_G}{L_f}} \quad (6)$$

Fig. 10 shows that the EV is going to tilt before it starts to slip. This is unwanted vehicle behaviour.

As every driver knows, it is easier to stop the vehicle and to gain control over the vehicle if slipping occurs before tilting. To lower the effect of vehicle tilting, manoeuvrability around the x-axis is added to this EV design. This manoeuvrability around the x-axis is the ability of EV to lean towards the inner (lower) radius when turning. By this leaning of the EV,  $L_G$  and  $L_f$  are changing their mutual ratios.

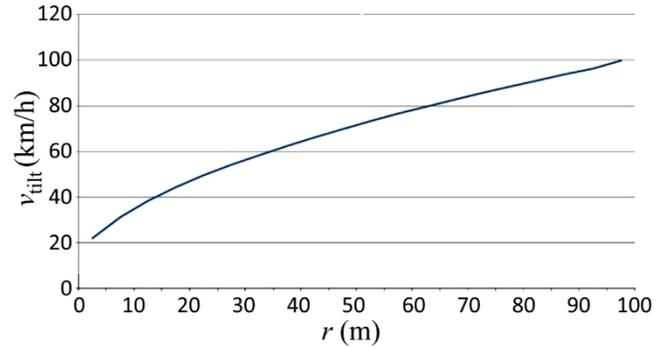


Figure 9 Maximal EV velocity before it starts to tilt

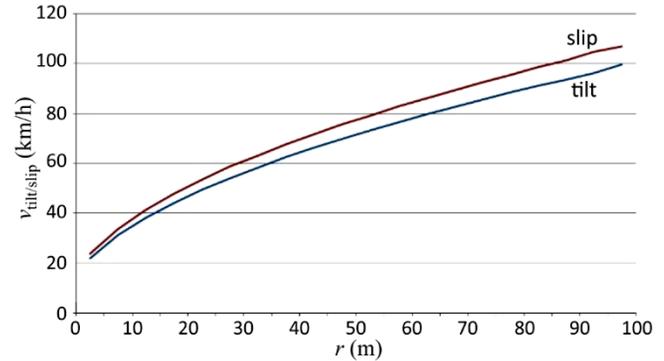


Figure 10 Maximal EV velocity before it starts to tilt and slip

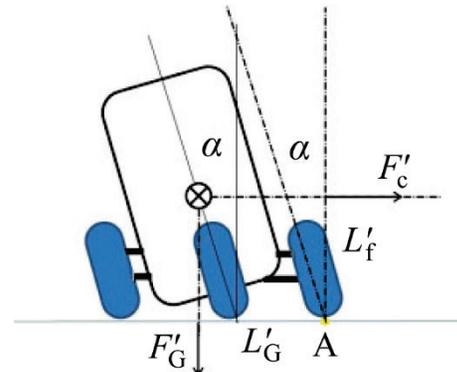


Figure 11 Changed  $L_G (L'_G)$  and  $L_f (L'_f)$  by EV leaning

By this leaning of the EV, Eq. (6) transforms into Eq. (7).

$$v'_{\text{tilt}} = \sqrt{\frac{r \cdot \mu \cdot g \cdot (L_G + L_G \cdot \sin \alpha)}{L_f \cdot \cos \alpha}} \quad (7)$$

As shown in Fig. 11, as the leaning angle ( $\alpha$ ) increases, so does the maximal EV velocity before tilting.

Combining Fig. 7 and Fig. 12 has shown at what lean angle the slipping of the EV will occur prior to tilting. It was discovered that  $\alpha \geq 15^\circ$  completely satisfies the requirement that the slipping of the EV occurs prior to tilting, as it can be seen in Fig. 13.

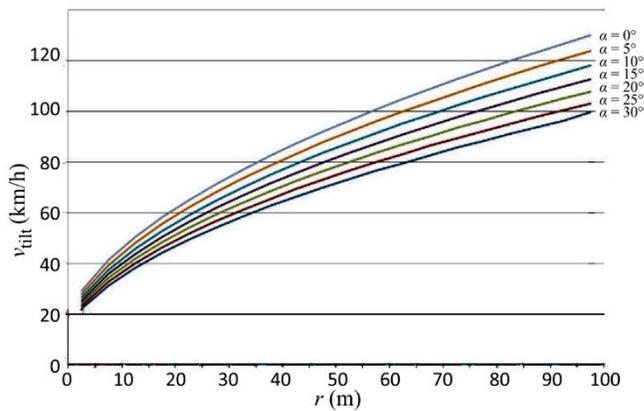


Figure 12 Maximal EV velocity before tilting at a different angle of leaning

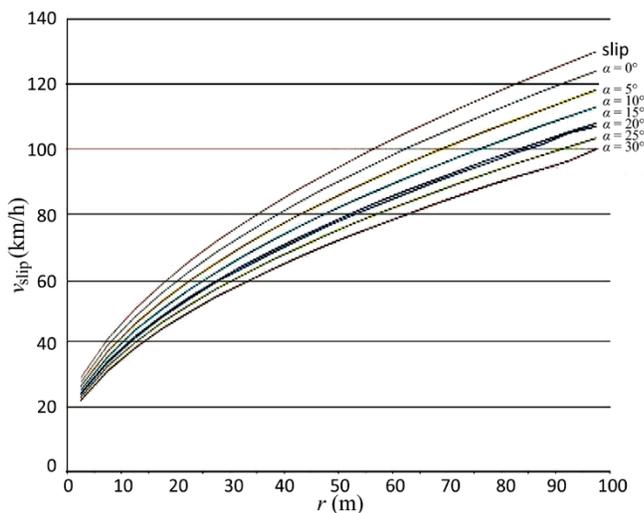


Figure 13 Necessary lean angle  $\alpha$  for EV stability

## 6 CONCLUSION

Research presented in this paper has demonstrated the feasibility of a 3-wheel EV. Research has shown that in order to satisfy the requirements of EV stabilities, it is necessary in this design to introduce manoeuvrability over the  $x$ -axis. This additional degree of freedom ensures that the tilt velocity is higher than the slip velocity. Scientifically, this research has opened the possibility for further design research of a simple, customizable EV.

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