A United Nations Safety Compliant Urban Vehicle Design

Marcelo R. G. Duarte, Marcilio Alves

Abstract—Pedestrians are the fourth group among road traffic users that most suffer accidents. Their death rate is even higher than the motorcyclists group. This gives motivation for the development of an urban vehicle capable of complying with the United Nations Economic Commission for Europe pedestrian regulations. The conceptual vehicle is capable of transporting two passengers and small parcels for 100 km at a maximum speed of 90 km/h. This paper presents the design of this vehicle using the finite element method specially in connection with frontal crash test and car to pedestrian collision. The simulation is based in a human body FE.

Keywords—Electric urban vehicle, finite element method, global human body model, pedestrian safety, road safety.

I. Introduction

DEATHS related to road traffic are epidemic and are growing continuously. In 2010 the global death rate per 100,000 population was 18.8 and although this rate was reduced to 18.2 in 2016, this was not sufficient to compensate the growth in population and quantity of cars. As a consequence, the absolute number of road related deaths continues to grow, going from 1.15 million in 2010 to 1.35 in 2016. In addition to that, vehicle related deaths are today the main cause of fatalities in children and young adults with ages between 5-29 years old [1]. More people die from car crashes than from HIV/AIDS, tuberculosis or diarrheal diseases, being the eighth main cause of mortality.

Vulnerable road users are disproportionally impacted by car accidents. Pedestrians, cyclists and motorcyclists are responsible for more than half of vehicle related deaths. Even so they are largely ignored in countries regulations. In Brazil, 8,200 traffic accidents with pedestrians were reported in 2013, which corresponds to 4.1 accidents per 100,000 inhabitants. Due to their vulnerability, the accidents tend to have more serious consequences, representing an important cause of morbidity and mortality.

From November, 2018 to October, 2019, 1408 pedestrians died only in the state of So Paulo, Brazil, an average of 3.86 per day in a year [2]. In the same period, 1895 motorcyclists and 1402 vehicle users died, making pedestrians the second group of traffic related obits in the state. Even being the fourth group that suffer accidents [3]. Pedestrians are extremely affected by road traffic, their accidents are much more harmful than those involving other kinds of transportation, but they are still disregarded in the regulations of many countries.

These aspects leads to the developing of a Safe Urban Vehicle (from Portuguese AUS). It is an electric United Nations Economic Commission for Europe (UNECE) crash regulations compliant ([4], [5]). In this paper it is presented the results of the numerical simulations to comply with pedestrian safety UNECE regulations. Instead of using the traditional anthropomorphic test devices (ATD), known as dummies, it is used a much more detailed numerical model based in Post Morten Human Surrogates [6]. These models give a more realistic response in a car crash simulation and more results can be obtained since tissues, organs, bones and ligaments can be modeled.

M. R. G. Duarte and M. Alves are with the Post Graduate Program of Mechanical Engineering, University of So Paulo, So Paulo, SP, 05508-030 Brazil (e-mail: marcelo.duarte@usp.br).

II. Numerical Models

A. AUS: A Safe Urban Vehicle

AUS is an electric vehicle (EV) that is being developed in Brazil to supply the lack of non-fuel based cars. In 2018 around 11,000 vehicles (less than 0.03%) of the Brazilian fleet were composed of EV while on developed countries the absolute number was of more than 5 hundred thousand ([7], [8]). AUS is being designed to be used in urban environment of big cities. The vehicles in these cities are used for transport of one or two persons from their homes to their jobs and then back home. Based on this, the vehicle is equipped with two seats but they are not aligned. This misalignment allows a width reduction. Besides it creates an empty space behind the driver used to carry daily shopping and/or small luggages. This space is very useful in a private car.

The vehicle, presented in Fig. 1, will have an autonomy of 100 km and a cruise velocity of 90 km/h. These requirements where adopted thinking in the daily use of an average person in a big city. This velocity is capable of perform well in any urban area and the space for daily shopping is important for a private vehicle. AUS was designed primarily with a tubular structure to be more effective and lighter. Front and rear crash boxes were used to mitigate collision damage to the passenger. It will have frontal and lateral air bags to ensure safety of the users. The batteries are positioned below the occupants, reducing the vehicle center of gravity and consequently making it more stable. Vehicle suspension is a McPherson type for all wheels. The idea was to use independent suspensions to let the car firm and to simplify the assembly.

B. GHBMC-Global Human Body Models Consortium

The human body model used in the crash simulations is based in a 50th percentile male characteristics [9]. To choose a suitable person 15 measurements of person's bodies where collected and if a standard deviation superior to 3% of the norm was encountered, the subjected was disregarded. In the end, a 26 year old, 175 cm and 78.6kg person was chosen to

Fig. 1 AUS finite element model

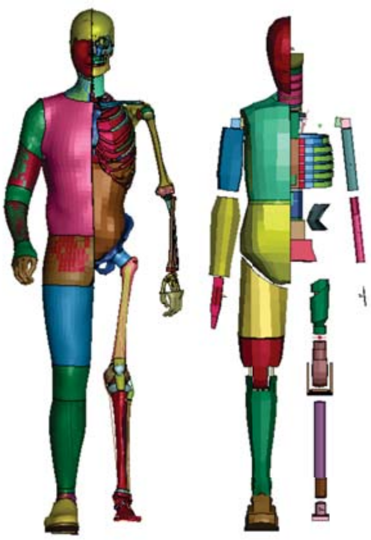


Fig. 2 GHBMC and dummy models

be the basis of geometric data [5]. A multimodality protocol was used to acquire the data in a pedestrian posture [10]. External anthropometry was collected via a three-dimensional scanner. The scans and external anthropometry were joined together to the creation of a non uniform rational basis spline (NURBS). With these information it was possible to model the subject in CAD format with 140 components. Model mesh was obtained with the CAD model and with the already existent mesh of a vehicle occupant (seated - M50-O). Two models were generated: one complete (M50-P) with finite elements more discretized and with internal organs modeled and one simplified (M50-PS) with longer elements and the internal organs represented by two “blocks” (one below the diaphragm and one above).

As the vehicle is still in its conceptual phase it was decided to make the simulations with the simpler model. The visual representation of the model and its comparison to the usual dummy models presented in Fig. 2.

III. UNECE Regulations and Results

A. ECE R127 - Pedestrian Safety Performance

The major task of this job was to perform the simulation of the car to pedestrian collision using the finite element method. Instead of the traditional dummies, it was used the model based on the human body with its constitutive relations and geometry based on a human being. The simulation was performed using LS-Dyna solver [11] and print screens of the simulation can be seen in Fig. 3

The main focus of the ECE R127 is on dummys knees and head. The knees are evaluated considering the maximum dynamic bending angle, that should not exceed 19 degrees, maximum knee shearing displacement, that should not exceed 6.0 mm and maximum acceleration in the top of tibia, that should not exceed 250 g. The criteria adopted to the head in the regulation is the Head Injury Criteria for 15 ms (HIC15), that should not be superior to 700.

Fig. 4 presents the acceleration of top of tibia. The result shows that the design complies with the requirements of ECE R127, since the maximum acceleration is inferior to 250 g. It was simulated too the impact with a legform impactor, that is the current requirement of the regulation. It is possible to observe that the accelerations of the human body model are significantly higher than the acceleration experienced by the legform impactor.

In the dynamic knee bending and in the maximum shearing displacement, the results were almost zero during the entire simulation for the legform impactor, so they will not be shown in the next figures. With this observation it is possible to conclude that the regulation is much more restrictive if the human body model is used. Besides that, it is possible to get results that were not possible to obtain using the legform impactor. Since it is now possible to use this kind of model, the regulations could be revised demanding the use of more complete finite element models.

Fig. 5 presents the knee bending angle calculated in the simulation. As it can be seen in the figure, this angle does not reach the maximum allowable value. Fig. 6 presents the shearing displacement of the dummys knee. The values are inferior than the limit imposed by the regulation, which is 6 mm.

Fig. 7 presents the acceleration of the head center of gravity. The calculated HIC15 to the head was 509.1. The allowable value is 700, so the model was approved in the HIC criteria.

With this analysis the model was able to be considered accepted by the pedestrian regulation. To continue the model evaluation frontal crash test was performed using the FEM to evaluate if the vehicle is able to comply with ECE R94 [4].

B. ECE R94 - Protection of the Occupants in the Event of Frontal Collision

The frontal crash test is the most traditional impact test to be performed in a vehicle. In this test the vehicle should impact a deformable barrier offset of its width by 40%. The vehicle should impact the barrier with a velocity of 56km/h.

The perspective view of the model used in the simulation is presented in Fig. 8.

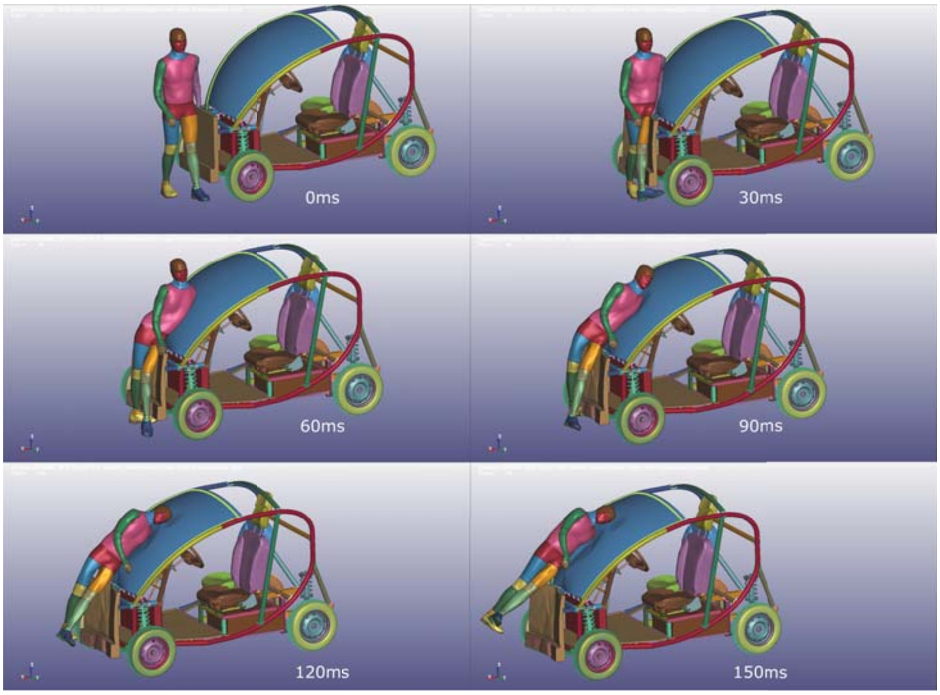


Fig. 3 Car to pedestrian collision print screens

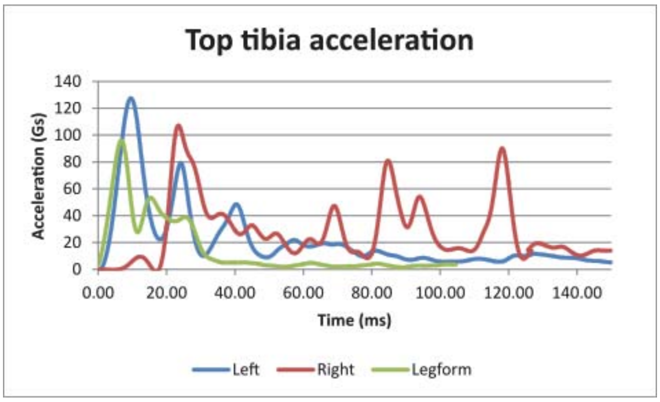


Fig. 4 Acceleration of top of Tibia

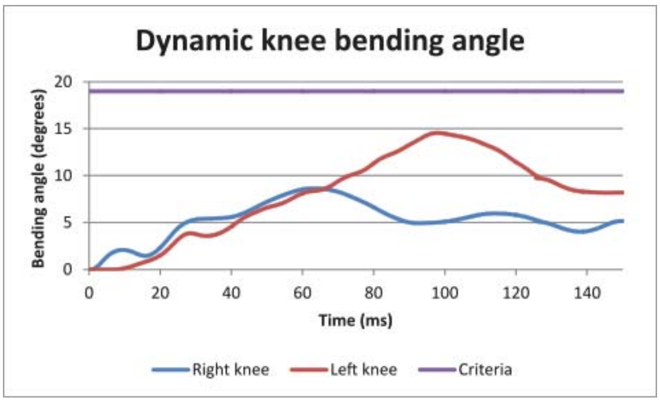


Fig. 5 Dynamic knee bending angle

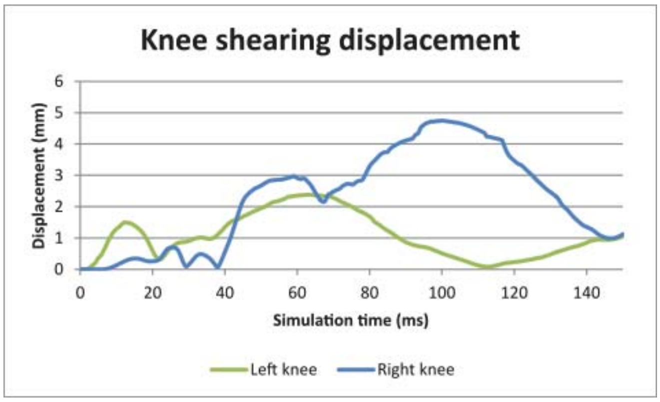


Fig. 6 Knee shearing displacement

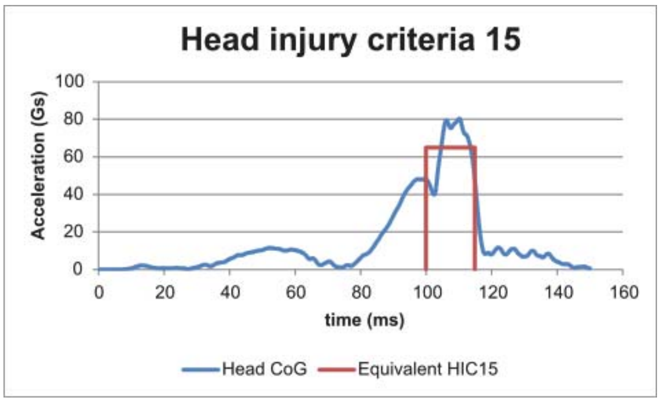
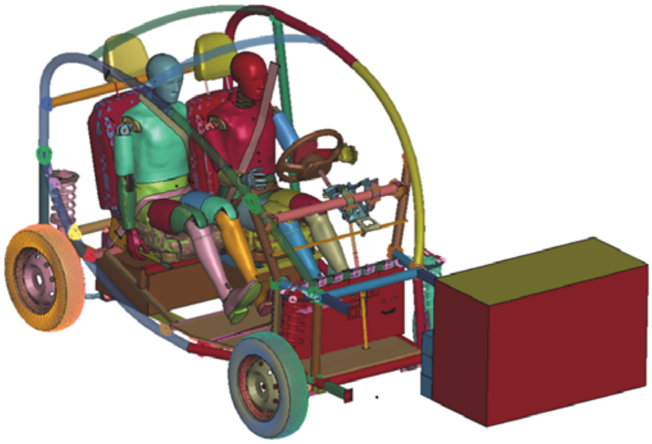


Fig. 7 Pedestrian head acceleration and equivalent HIC

Both driver and passenger were analyzed in the simulations but only the driver's results will be presented since its values were always superior to the values calculated to the passenger. This is due to the impact to occur of the driver's side so its

Fig. 8 AUS model colliding with ODB40% with two occupants



deceleration is more significant than the one experienced by the passenger.

The first criterion evaluated was the HIC and head acceleration. HIC should not exceed 1000 and the head acceleration should not exceed 80g for more than 3ms. The calculated values for the acceleration are presented in Fig 9

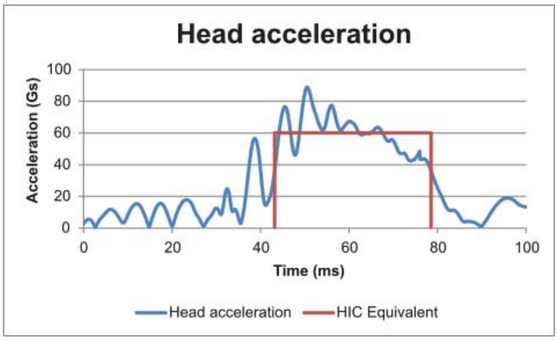


Fig. 9 Driver head acceleration and equivalent HIC

The presented plot shows that the head acceleration was superior to 80g from 49.7 to 51.5 ms. This difference is equal to 1.8ms. So the 3 ms criterion was accomplished. The HIC calculated was 981, which is inferior to the 1000 required by the regulation. The equivalent HIC indicates what would be a constant deceleration that would result in a 1000. This representation is very usual in head injury evaluations.

Figs. 10 and 11 present the calculated forces in the driver neck. With the limits established by ECE R94. It is possible to see that in none moment the forces disrespect what is required by the regulation.

The other evaluated criteria that are required by the ECE R94 do not involve the time in its evaluation, just a maximum value or a calculated criterion. For this reason the graphs containing the calculated results will not be presented. The summary of results are presented in table I.

As was presented, the vehicle is able to comply with the United Nations Economic Comission for Europe for car to pedestrian collision and frontal impact.

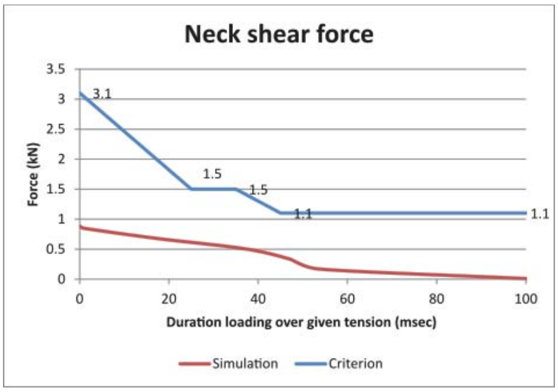


Fig. 10 Neck shear forces

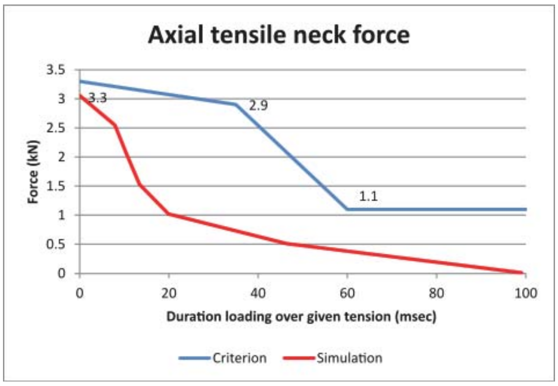


Fig. 11 Neck tensile forces

IV. Conclusion

The vehicle is still under development, but the results shows that it is possible to design an electric and compact vehicle able to comply with international safety regulations. With this the impact in urban pollution would be reduced and the deaths related to traffic injury could fall significantly. Besides that, as the vehicle has width and length lower than the measures of traditional vehicles, the traffic jams, that are nowadays a huge problem in urban conglomerates could be impacted too.

It is possible to conclude too that the regulations concerning pedestrian safety are quite permissive when using the traditional dummies in the impact. The Global Human Body Model used to evaluate the car to pedestrian collision showed much more aggressive values of acceleration or displacements.

The next steps of the vehicle are to simulate rear impact [12] and lateral pole performance [13].

TABLE I
RESULTS SUMMARY

Criterion	Norm value	Calculated value	Compliance
Neck bending moment about y axis	Not to exceed 57Nm	51Nm	Ok
Thorax compression criteria	Not to exceed 42mm	41 mm	Ok
Femur force	Not to exceed 7.58 kN	2.1 kN	Ok
Tibia compression force	Not to exceed 8kN	5.6 kN	Ok
Tibia index	Not to exceed 1.3	0.891	Ok
Movement of sliding knee joints	Not to exceed 15mm	7.2 mm	Ok

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