
Finite Element Study of Head and Chest Injuries in Vehicle Frontal Crashes

By

Ibrahim Abdullahi Rafukka, PhD

Department of Mechanical Engineering,
Bayero University, PMB 3011, Kano, Nigeria

*Email: ibrahimrafukka@yahoo.com

ABSTRACT

Finite element (FE) analysis has been applied extensively in the investigation of biomechanical behaviour of human beings in vehicle crash. Specifically, this work, utilizes FE crash simulations to examine the injuries sustained by vehicle occupant for head and chest during frontal impact. LS DYNA software was used to carry out the dynamic simulations using Hybrid III (HIII) dummy model. The effect of speed on the injuries sustained by vehicle occupant on the head and chest was studied. The results indicate that head injury criteria (HIC) and chest acceleration increased with increased in impact speed. Speed of 40 km/h was found to have injury values lower than thresholds for head and chest. High severity of injuries was obtained at higher impact speeds of 46 km/h, 56 km/h and 64 km/h. Crash test was also carried out to determine the effect of airbag in reducing injury levels to the occupant. Air bag drastically minimizes the HIC and chest acceleration. Therefore, the study provides useful information to road safety agents and vehicle designers and users.

Keywords: Crash; Crash dummy; Finite element; Head injury criteria

INTRODUCTION

Traffic accident has become a menace that claims millions of lives worldwide. Frontal crash has been reported to be the most common accident happening on the roads where the vehicle collides with rigid barriers such as wall and road safety rails etc (ANCAP 2016). Speed is the major factor responsible for severity of injuries in vehicle accidents (Agbonkhese et al. 2013; Ratanavaraha & Suangka 2014). Injuries to the head and chest are resulted due to impact of human body with vehicle interior. Many studies have identified traffic accident as the major cause of head and chest injuries based on the cases reported in the Nigerian hospitals (Jasper et al. 2014; Oboirien & Ukwuani 2016; Ogunrombi et al. 2012; Gwaram et al. 2013). Studying the effect of speed on the injury

severity in frontal vehicle crash is difficult because of complexity associated with getting the accident data. Crash test is the standard method used by automotive engineers to study injuries sustained by occupant in crash scenarios.

Crash test can either be done experimentally or using numerical simulations. Although, experimental crash test using actual vehicle provides genuine and accurate data about the injuries, the approach is very costly and complex. Also, because of ethical reasons real human being can not be applied in testing vehicle safety (Teng et al. 2008). Crash test dummies (Anthropometric test devices) that simulate human response are used in the evaluation of safety performance of vehicles. They are instrumented to record data of dynamic behaviour of various

human body part in different impact conditions (Maurath et al. 2010). FE models of crash dummies representing various ages have been developed and validated for crash simulations. Numerical simulation is a useful tool in investigating the biomechanical response of human body and sustained injuries during crash. Finite element simulation has been extensively applied by many researchers in crash analysis (Yadav & Pradhan 2014; Soni et al. 2014; Shasthri et al. 2016). Well validated vehicle and crash dummy FE models are used to replicate a given crash events and injury parameters are evaluated and compared to the standards for the assessment of vehicle crashworthiness.

Full vehicle test is very costly as such a sled representative is often applied

in crash test. Acceleration pulse of the vehicle is applied to the sled which is carrying the belted dummy on the vehicle seat as shown in Figure 1. Mohan et al. (2010) carried out Validation of HIII dummy FE model in sled test at 56 km/h. HIII dummy kinematics response at various points of simulation was found to be in good agreement with experimental sled test as shown in Figure 1. The neck, upper and lower limbs extensions were similar and head, chest and thorax acceleration peak values were shown to be in good correlation (Mohan et al. 2010). This confirms that HIII dummy FE model is valid for studying injury biomechanics of vehicle occupants in sled test.

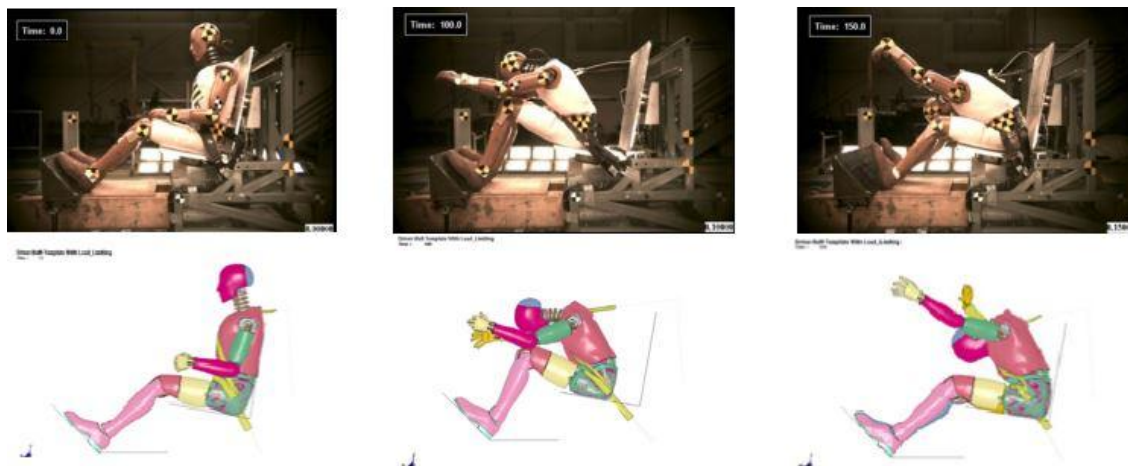


Figure 1 Biomechanical response comparison of physical crash dummy and FE model on a sled (Mohan et al. 2010)

Frontal crash simulation has been studied by many researchers for vehicle safety performance evaluation (Abdel-Nasser et al. 2013; Donga 2011; Elmarakbi et al. 2013; Ning 2014; Soni et al. 2014). Very limited studies were carried out in regards to the effect of speed on injuries severities in frontal crashes. This study utilizes the FE crash simulation using adult crash dummy FE model on a sled to study the

effect of speed on the head and chest injuries. This will provide road users, car manufacturers, health practitioners and road safety stakeholders with useful information on how to establish solutions to crash problems.

METHODOLOGY

Sled test is conducted with belted dummy to evaluate its response in an

environment that is similar to real car crash. The sled model consists of floor, the seat, knee bolster, steering system, air bag, and seat belt system. HIII dummy model was incorporated in to the restraint system and contacts are defined between dummy and seat, air bag and steering system. The

dummy is seated and secured by safety belt which consists of shoulder and left belt as shown in Figure 2. Acceleration pulse was applied to the rigid seat in the negative x-direction, while constrained in y and z direction for translation and rotation

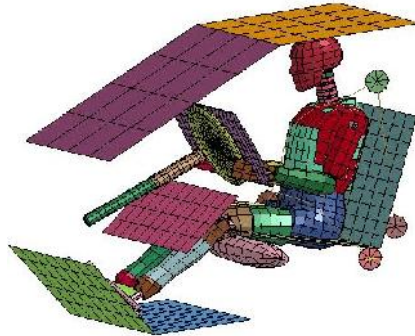


Figure 2 Crash dummy FE model secured on the sled

Airbag was modelled using *AIRBAG_WANG_NEFSKE in LS DYNA where the airbag is considered as a control volume enclosed by fabric. Geometry of airbag and gas properties were obtained from 1992 Taurus FE model developed and validated by NCAC (2015). Modelling of seatbelt system involves fabric, D-ring and retractor. Seatbelt harness was modelled using MAT_SEATBELT and airbag was modelled using MAT_FABRIC in LS DYNA.

Impact velocities were applied to the sled as BOUNDARY_PRESCRIBED_MOTION_RIGID. AUTOMATIC_NODES_TO_SURFACE contact algorithm is applied between dummy and airbag and steering column system. The contact between dummy and seat, floor and knee bolster were defined

using RIGID_BODY_ONE_WAY_TO_RIGID_BODY option in LS DYNA. The dummy was positioned in the seat and the constant downward gravity was applied in z-direction. Post process was run using LS DYNA software with total computation time of 8 min. Head and chest acceleration-time histories were recorded from accelerometers located in head and chest of the HIII dummy FE model as history nodes (1 and 1787) shown in Figure 3. The pre- and post-processing analyses were conducted with LS PREPOST (v4.2). A channel frequency class (CFC) filter 108 was applied to remove noise for the simulation results in accordance with SAE J211.



Figure 3: Head and chest accelerometer nodes of HIII dummy FE model (LSTC 2017)

The dummy model was developed and validated by Livermore Software Technology Corporation (LSTC) for frontal crash test simulations and made available for LS DYNA users for research and design purposes. It is capable of predicting injuries for various body locations such as head, neck, chest, pelvic and femur.

Injury in the head can cause brain concussion or affect some sensory organs (Ji 2015). HIC is the main criteria used in assessing the head injury risk on impact. It is the standardized maximum integral of head acceleration measured at the CoG within a specified time window. It is calculated based on the equation (Henn 1998; Bois et al. 2004):

$$HIC_C = \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a_{result} \cdot dt \right]^{2.5} \cdot (t_2 - t_1) \quad (i)$$

Where t_1 and t_2 are the time duration of crash within which the head acceleration was maximum. Acceleration is measured in unit of acceleration of gravity (g) and time in seconds. LS DYNA computes the HIC based on 15 ms and 36 ms windows which yields HIC_{36} and HIC_{15} respectively. HIC_{36} is considered in the present study and is referred as HIC.

Simulation was carried out using speed 40, 48, 56 and 64 km/h and HIC and chest acceleration time histories were recorded. Further test was done at 40 km/h without air bag for the purpose of comparison to show the effect of airbag system in reducing injuries in frontal crashes. Simulations are analysed for time duration of 150 ms which is enough to observe the dummy response and

interaction with steering column, air bag and seat belt.

RESULTS AND DISCUSSIONS

Speed of the vehicle was known to have greatest effect on the injury severity during crash. Figure 4 shows that HIC increases with increase in vehicle impact speed. Deceleration of vehicle on impacting a frontal rigid barrier is transmitted to the occupant. The sled experienced the change in velocity as a result of the car frontal impact. For low change in velocity of 40 km/h, HIC was 379.5 which is within the accepted limit of 1000 for adult occupant (Eppinger et al. 2000) therefore, at this speed, no head injuries are expected. However, the severity of injury was said to increase with increase in speed. HIC experienced by dummy FE

model for 48 km/h, 56 km/h and 64 km/h, were higher than the threshold values. This means that the vehicle occupant was subjected to higher decelerations which eventually causes serious head injuries.

Since seat belt and airbag were used in this study, controlling the speed to lower levels will lead to lower impact decelerations which could help in reducing the injury severity.

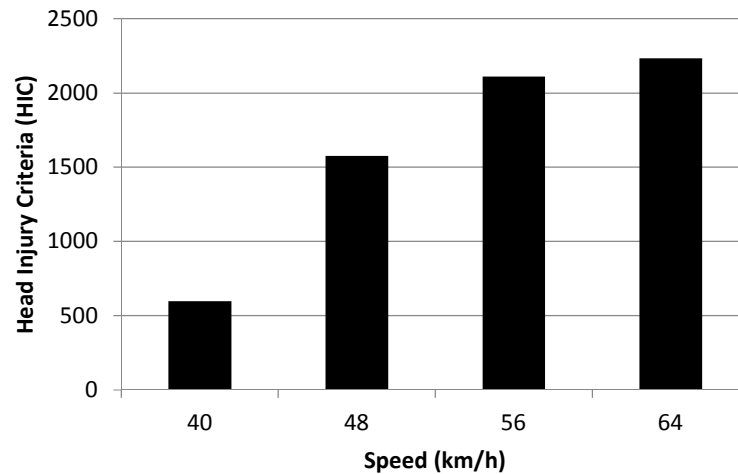


Figure 4: Head injury criteria (HIC) versus vehicle speed for adult driver

Severity of injury sustained by vehicle occupant on the chest in vehicle crash is expressed in terms of chest acceleration. Figure 5 shows that acceleration increases as the speed of impact increases. When the vehicle impacts rigid wall at 40 km/h, the acceleration experienced by the chest was about 50 g which is reasonably below an

acceptable limit of 60 g for adult occupant (Eppinger et al. 2000). However, for higher impact speeds of 48 km/h and 56 km/h the chest acceleration on the dummy chest was higher than acceptable threshold. At 64 km/h dummy chest experienced high acceleration which is an indication of severe injuries sustained by the occupant at this speed.

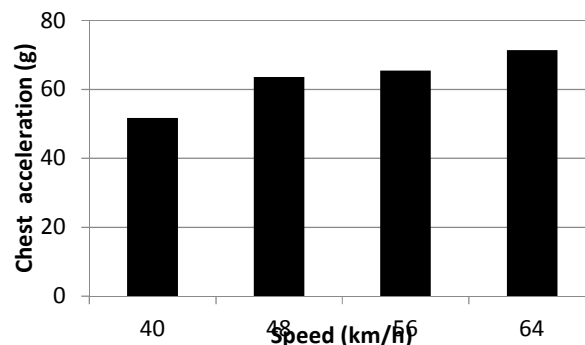


Figure 5: Chest acceleration versus vehicle speed for adult driver

To further study the effect of airbag on the severity of injury in frontal impacts, FE simulation was conducted without the airbag at a velocity of 40km/h. HIC and chest acceleration were recorded as 7359 and 60.84 g respectively. High HIC value experienced by dummy head is as a result of dummy head impacting the steering wheel as shown in Figure 6 a. The occupant is subjected to high HIC values which are

about seven times higher than recommended threshold. Chest acceleration was not very high even without air bag. This is because of the protection offered by seat belt to the dummy chest which prevents it from contacting the steering column. Figure 6b shows the frontal crash response of the dummy at 40 km/h with airbag in position.

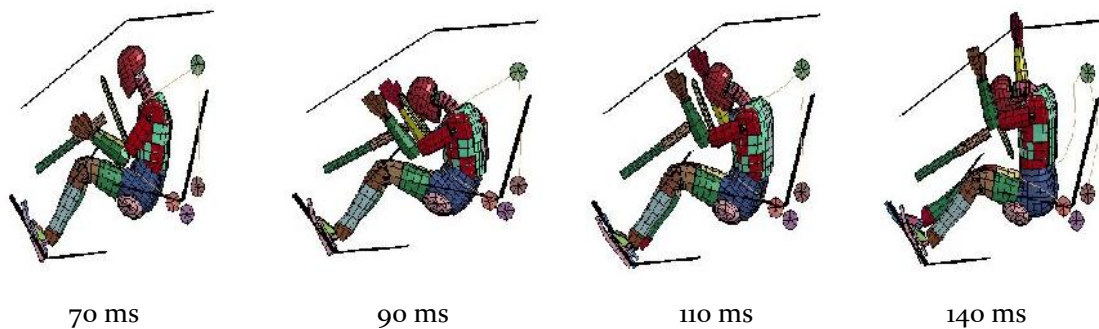


Figure 6a Dummy response without airbag

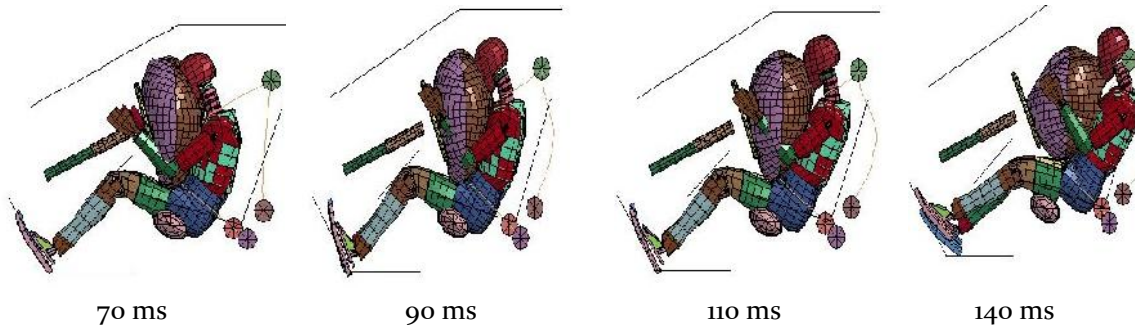


Figure 6b Dummy response with airbag

Figure 6 a & b: Crash dummy model response at some points in the simulation

It can be obviously seen in Figure 6b that the dummy head impacts the air bag instead of the steering column which absorbs the impact energy there by reducing HIC to 379.5 which is far below the threshold, and this ensures the survival of the vehicle occupant from head injuries. Dummy head had contact with steering column at 90 ms and 140 ms as seen in Figure 6a which exposed the dummy to very severe situation as can be seen by the

high neck bending as compared to when air bag was applied.

The effectiveness of air bag in reducing severity of injuries was also confirmed by (Pintar et al. 2000) who shows that brain injuries of driver and right front seat occupant reduced substantially with air bag and seat belt for all impact speed, based on accident data in U.S.

CONCLUSIONS

In this study the speed of vehicle at impact was found to affect the injuries sustained by the occupant. HIC and chest acceleration values increased as the vehicle impact velocity increased. Also, air bag is useful in reducing injury severities in frontal crash event. It is therefore necessary to ensure favourable vehicle speed limit on the roads. Because the lower the driving speeds the lower will be the severity of injuries. The information from current work will assist vehicle designers in producing safer vehicles and restraint system. It also provides effects of speed on injury severities in quantitative manner which is essential in establishing safety rules and standards. Vehicle users will also know the negative effect of driving at high speed and dangers of using vehicle with faulty air bag systems.

REFERENCES

- Abdel-Nasser, Y., Alrajhi, J. & Alardhi, M., (2013). Frontal crash simulation of vehicles against lighting columns in Kuwait using FEM. *International journal of*.
- Agbonkhese et, 2013. Road Traffic Accidents in Nigeria : Causes and Preventive. *Civil and Environmental Research*, 3(13), pp.90–100.
- ANCAP, (2016). ANCAP Safety Ratings. Available at: <http://www.ancap.com.au> [Accessed July 12, 2016].
- Bois, P. Du et al., 2004. *Vehicle and Occupant Protection* P. Prasad & J. E. Belwafa, eds., American Iron and Steel Institute.
- Donga, A., (2011). *Application of Sandwich Beam in Automobile Front Bumper for*. Wichita State University.
- Elmarakbi, A. et al., (2013). Crashworthiness of vehicle-to-pole collisions using a hybrid III three-year-old child dummy. *International Journal of Vehicle Systems Modelling and Testing*, 8(1), pp.1–37.
- Eppinger, R. et al., (2000). *Suppliment: Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems - II*,
- Guha, S., 2014. *LSTC _ NCAC Hybrid III 50 Dummy*,
- Gwaram, U., Ihezue, C. & Onche, I., (2013). Assessing the severity of injury using the revised trauma score in a tertiary institution in North-Central Nigeria. *Nigerian Journal of Basic and Clinical Sciences*, 10(1), p.3.
- Henn, H., (1998). Crash Tests and the Head Injury Criterion. *Teaching Mathematics and its Applications*, 17(4), pp.162–170.
- Jasper, U.S. et al., (2014). The epidemiology of hospital-referred head injury in Northern Nigeria. *Journal of Sientific Research & Reports*, 15(3), pp.2055–2064.
- Ji, J., 2015. *Lightweight design of vehicle side door*. Politecnico di Torino.
- LSTC, (2017). Livermore.
- LSTC, (2013). *LSTC Hybrid III 6 year old Finite Element Model Documentation*,
- Maurath, C. et al., (2010). Overview of LSTC's LS-DYNA Anthropomorphic Models. In *11th International LS-DYNA Conference*. pp. 41–52.
- Mohan, P. et al., 2010. LSTC / NCAC Dummy Model Development. , pp.53–64.
- NCAC, (2015). Application: Finite element model archive. Available at: <http://www.ncac.gwu.edu/vml/model s.html>.
- Ning, L., (2014). *Finite Element Modeling and Simulation of occupant response in Highway Crashes*. University of

- North Carolina.
- Oboirien, M. & Ukwuani, S., (2016). The Conundrum of Polytrauma in Sokoto, North-West Nigeria. *Journal of Trauma & Treatment*, 5(2), pp.5-7.
- Ogunrombi, A.B. et al., (2012). The Pattern and Outcome of Chest Injuries in South West Nigeria. *The ANNALS of African Surgery*, 9(2), pp.201215-201220.
- Pintar, F.A., Yoganandan, N. & Gennarelli, T.A., (2000). Airbag effectiveness on brain trauma in frontal crashes. *Annual proceedings / Association for the Advancement of Automotive Medicine. Association for the Advancement of Automotive Medicine*, 44, pp.149-169.
- Ratanavaraha, V. & Suangka, S., (2014). Impacts of accident severity factors and loss values of crashes on expressways in Thailand. *IATSS Research*, 37(2), pp.130-136.
- Shasthri, S. et al., (2016). A parametric Study of Neck Moment Response in a 3 Year Old Child Subjected to Oblique Side Impact. *ARPN J. Eng. Appl. Sci.*, 11(8), pp.5126-5133.
- Soni, R., Parmar, S. & Sharma, S., (2014). Airbag Performance Simulation Using Finite Element and Impact Biomechanics Methods for Human Injury Prevention During Accident of Vehicles. *International Journal of Biomedical Engineering and Science*, 1(2), pp.15-22.
- Teng, T.L. et al., (2008). Analysis of dynamic response of vehicle occupant in frontal crash using multibody dynamics method. *Mathematical and Computer Modelling*, 48(11-12), pp.1724-1736.
- Yadav, S. & Pradhan, S.K., (2014). Investigations into dynamic response of automobile components during crash simulation. *Procedia Engineering*, 97, pp.1254-1264.