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Comparing Occupant Injury in Vehicles Equipped with and without Frontal Airbag

Y. Ahmad*[1], K. A. Abu Kassim[1], M. H. Md Isa[1] and S. Mustaffa[1]

[1]ASEAN NCAP Operationalization Unit, Malaysian Institute of Road Safety Research (MIROS), 43000 Kajang Selangor, Malaysia

Corresponding author: yahaya@miros.gov.my

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Abstract – *Most vehicle structures have been designed to withstand crash impact during an accident. The front area of the vehicle will crumple to absorb crash energy while the passenger compartment remains intact to protect the occupant inside. In addition, restraint system inclusive of airbag and seatbelts has been integrated in vehicles to further enhance the occupant's protection. However, in certain cases, the airbag is removed due to cost saving by car manufacturers. Although the frontal airbags have been removed, the structure remains the same. This can be observed from the crash tests conducted by ASEAN NCAP on two variants of the same car model which are fitted with and without airbags, where the cars obtained two different rating. This case study compares and presents occupant injuries for both variants.*

Keywords: Airbag, ASEAN NCAP, crash test

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1.0 INTRODUCTION

Vehicle crash or collision can be divided into three phases. The first phase involves collision between the vehicle and another object. The second phase is the collision between occupant and the vehicle interior while the last phase is the collision involving the human internal organs. Many technologies have been developed to manage crash energy in order to protect vehicle occupants during a crash. The energy of the crash has been managed through designing the crumple zone for the first phase. In addition, supplementary system such as airbag system is designed for protecting and restricting occupant kinematic during the crash. Finally, for the third phase, the energy transfer to the body and internal organs has been limited within the capability of human injury tolerance.

Vehicle safety criteria must be considered from the early stage of development in order to produce safer cars to protect occupants during the crash. Vehicle structural design is very important during the first phase of collision. This is because the design is required to absorb energy to soften the impact as well as to maintain compartment integrity, which is also the occupant survival space. Occupant injuries inside the vehicle are influenced by the vehicle deceleration (pulse); hence modifying the deceleration peak level will naturally reduce the impact to the occupant (Motozawa & Tahahiro, 2000; Motozawa et al., 2003; Jiri, 2000). Vehicle structural performance is also very important in determining safety level. As such, various studies have been conducted to determine the relationship between vehicle pulse and the loading to the dummy using different parameters and tools (Huang, 2002; Gearhart, 2001; Sparke & Thomas, 1994; Lundell, 1984).

In the second phase of collision, energy transfer to the occupant will be absorbed by the interior components, commonly known as Supplementary Restraint System (SRS). This system includes airbags, seatbelts and other components to limit kinematic movement of the human body and protect it from impacting hard and sharp object. Various studies have also been conducted on the effectiveness of airbag and seatbelts. The three-point seatbelt, without the use of airbag, is estimated to reduce probability of fatality and injury by 40-45% and 80% respectively (NHTSA, 1999; Cummings et al., 2003a). Combination of seatbelts and airbag will further increase protection and reduce the risk of fatalities by 68% (Cummings et al., 2003b). However, modern vehicle development requires the combination of seatbelts, airbag, seats and other components to improve protection and further reduce the risk of injury and fatality.

At present, most vehicles are developed to meet crash safety performance criteria either stipulated in regulations or by the New Car Assessment Program (NCAP). These criteria include good crash performance structure, restraint system such as airbag and other supplementary safety systems. However, due to unknown reasons, the airbag has become an option for certain models. This means the airbag is not standard equipment. Thus, this case study compared the performance of two variants of a car model that come with and without airbag. They were tested in accordance to the frontal crash test protocol of the New Car Assessment Program for Southeast Asian Countries (ASEAN NCAP). Occupant injury outcome will then be compared for both cars to demonstrate the effectiveness of the airbag system.

1.1 ASEAN NCAP Frontal Crash Test

One of the requirements in ASEAN NCAP rating is frontal Offset Deformable Barrier (ODB) crash test (Abu Kassim & Mohd Jawi, 2014). In this crash test, a vehicle is propelled toward a stationary barrier at an impact speed of 64 km/h. The impact should cover 40 percent of vehicle face on the driver's side. An illustration of the crash configuration is shown in Figure 1.

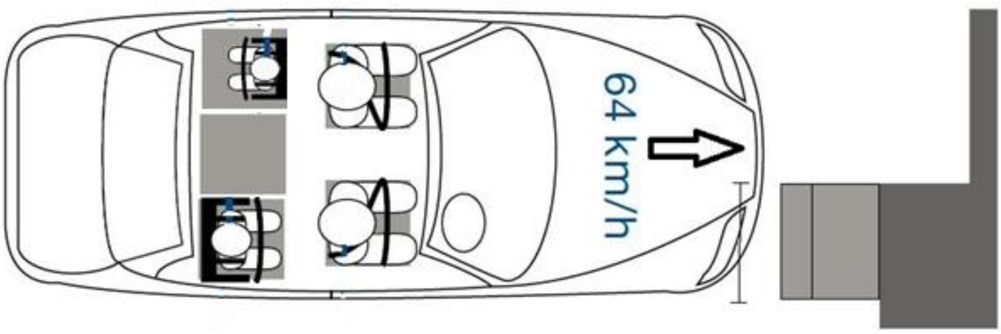

Figure 1: ASEAN NCAP frontal offset crash test configuration

This crash test configuration is adopted from the Euro NCAP. Two instrumented Hybrid III dummies occupy the front seats as the driver and front passenger. In addition, two child dummies were installed in the rear seats. The impact speed of 64 km/h was chosen on the basis of accident analyses carried out for EEVC Working Group 11, developed for the European test procedure. An analysis of available frontal impact accident research concluded that a crash test, which replicated a car to car crash at 55 km/h, would address just under half of the serious and fatal casualties which is AIS≥3 (Hobbs & McDonough, 1998).

2.0 METHODOLOGY

Data from the ASEAN NCAP frontal offset crash test will be used for comparison. The vehicles selected were two variants of the same model with the only difference being the airbag. Both variants were tested separately. The first car was equipped with frontal airbag while the second car was not fitted with frontal airbag. As mentioned earlier, crash test setup was based on the ASEAN NCAP test protocol for frontal offset crash test (ASEAN NCAP, 2015).

Injury data was collected from two Hybrid III adult dummies installed as the driver and front passenger inside the vehicle. Upper extremities injuries were compared to determine the injuries suffered by the occupants for both cases. Head injuries were collected through the accelerometer installed inside the head at the center of gravity. The injury sustained to the head during an accident has been known to be the leading cause of death and disability. There are two criteria used for measuring head injuries in NCAP and regulation crashes, namely Head Injury Criterion (HIC) 36 and head resultant acceleration exceeding 3ms.

2.1 Calculation of HIC

The HIC formulation was proposed by the US National Highway Traffic Safety Administration (NHTSA) and is included in the US regulation FMVSS No. 208 which is based on Wayne State Tolerance Curve (WSTC) (Hobbs et al., 1998). HIC is computed based on the following formula:

$$HIC = \left(\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt \right)^{2.5} (t_2 - t_1) \qquad (1)$$

Here, t_2 and t_1 are any two arbitrary times during the acceleration pulse. Acceleration is measured in multiple of the acceleration gravity (g) and time is measured in seconds (Eppinger et al., 1999).

2.1 Calculation of 3ms Criterion

The “3ms criterion” is also based on the WSTC. It is defined as acceleration level obtained for impact duration of 3ms. It should not exceed 80g (Schmitt et al., 2013). This threshold value is also incorporated in the regulations dealing with impact of the occupant to the interior structures of a vehicle and the impact to head restraints. This injury criterion has been developed to address mechanical responses of crash test dummies in terms of risk to life or injury to a living human.

According to Schmitt et al. (2014), they are based on an engineering principle that states that the internal responses of a mechanical structure (regardless of its size, or the material it is composed from), are uniquely governed by the structure's geometric and material properties together with the forces and motions applied to its surface. The criteria have been obtained from experimental efforts by using human surrogates in which both measurable engineering parameters and injury consequences are observed. Statistical techniques are then used to determine the most meaningful relationships between forces/motions and resulting injuries.

3.0 RESULTS AND DISCUSSION

This section will include result analyses and discussion of vehicle crash pulse, head injury and chest injury comparisons.

3.1 Vehicle Crash Pulse Analysis

The vehicle crash pulse was collected and compared as shown in Figure 2. Data was collected from the accelerometer installed at the bottom of the B-pillar of the vehicle. The energy absorbed by the vehicle as represented by the graph showed similar patterns and peak for both vehicles. This shows that both vehicles experienced the same crash pulse and energy.

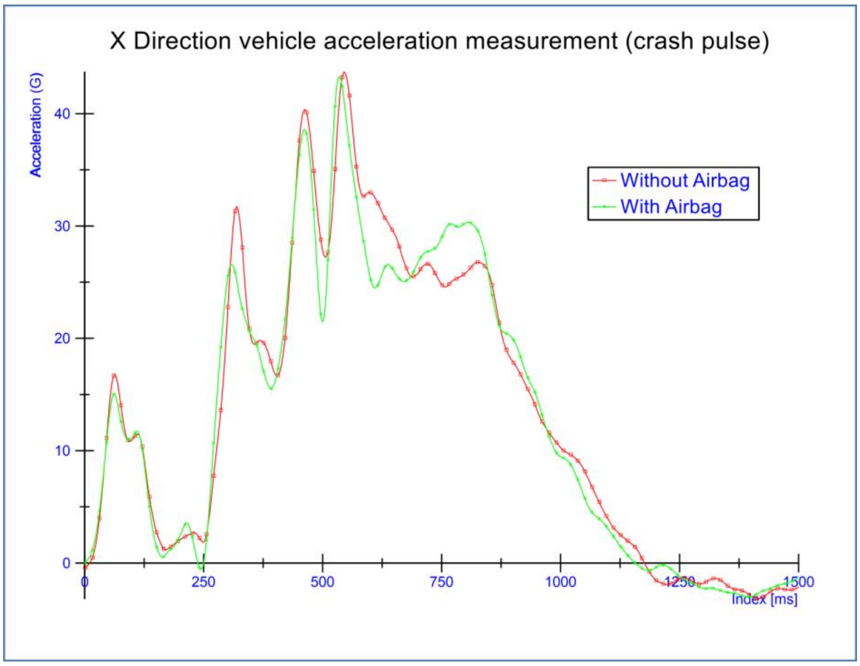

Figure 2: Vehicle crash pulse

The same results for both crash tests proved that both vehicles had the same structure. No modification was done to the structure. The only difference is that one vehicle had the airbag system while the other did not come with the system.

3.2 HIC Comparison

The most critical region in the human body is the head. Severe injury to the head can lead to fatality. In the crash test, head injury was measured using three axial accelerometer installed at the center of gravity of the head. Figure 3 shows resultant acceleration measurements for the driver's side. Head and brain injury was measured using Head Injury Criterion (HIC) over a maximum interval of 36 milliseconds and the peak acceleration within 3 milliseconds (Eppinger et al., 1999). HIC is derived from the resultant acceleration curve. For the vehicle without airbag, HIC36 was recorded at 1908 with 3ms Peak Acceleration of 121.28 G. On the other hand, HIC36 was recorded at 234.83 with 3ms peak acceleration of 40.66 G for the vehicle with the airbag system. This shows that installing driver airbag into the vehicle significantly reduces head acceleration.

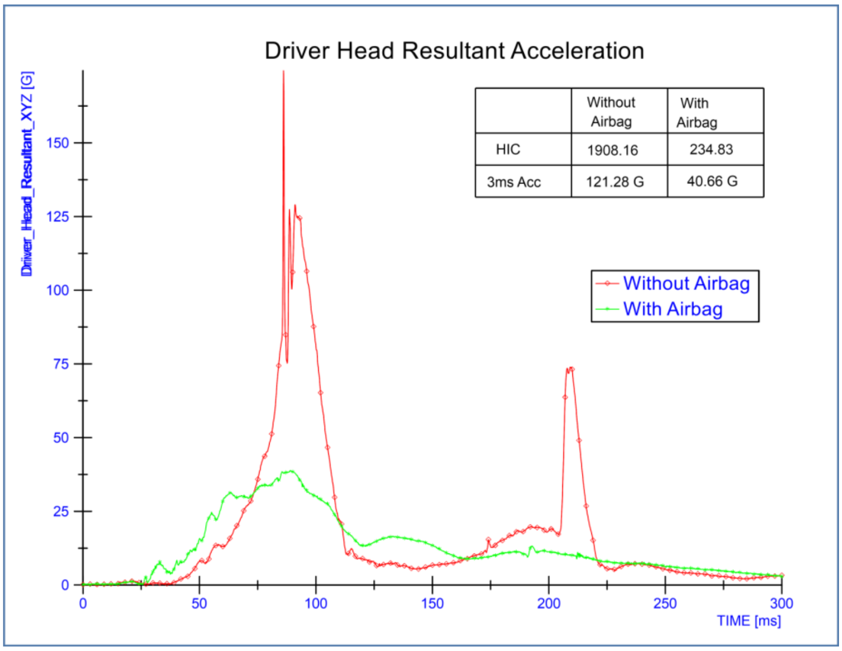

Figure 3: Driver head resultant acceleration

HIII 50th percentile adult dummy was also installed in the front passenger's side of the car in the crash test. The head acceleration resultant results are presented in Figure 4. 3ms peak acceleration for the vehicle without airbag was recorded at 61.00 G while HIC36 was calculated at 646.90 G. Upon installing the passenger airbag system, 3ms peak acceleration was reduced to 47.98 G with the calculated HIC36 at 335.47.

NCAP requires the HIC time interval to be 36ms (thus called HIC36). The maximum value of 1000 will be the limit for adult 50th-percentile male. The "3ms criterion" is based on the WSTC. It is defined as acceleration level obtained for impact duration of 3ms and should not exceed 80g (Schmitt, 2013). This threshold value is also incorporated in the regulations dealing with impact of the occupant to the vehicle interior structure and the impact to head restraints.

HIC and 3ms Acceleration for the variant without airbag exceeded the limit value in both cases because the head hit the steering wheel during the crash. It was a hard contact that recorded a very high peak. The value decreased dramatically under the threshold limit for the variant with the airbag system. In the passenger's case, both occupants' head maintained a value which was lower than the limit, as there was no hard contact during the crash. Hence, there is no sharp peak in Figure 4.

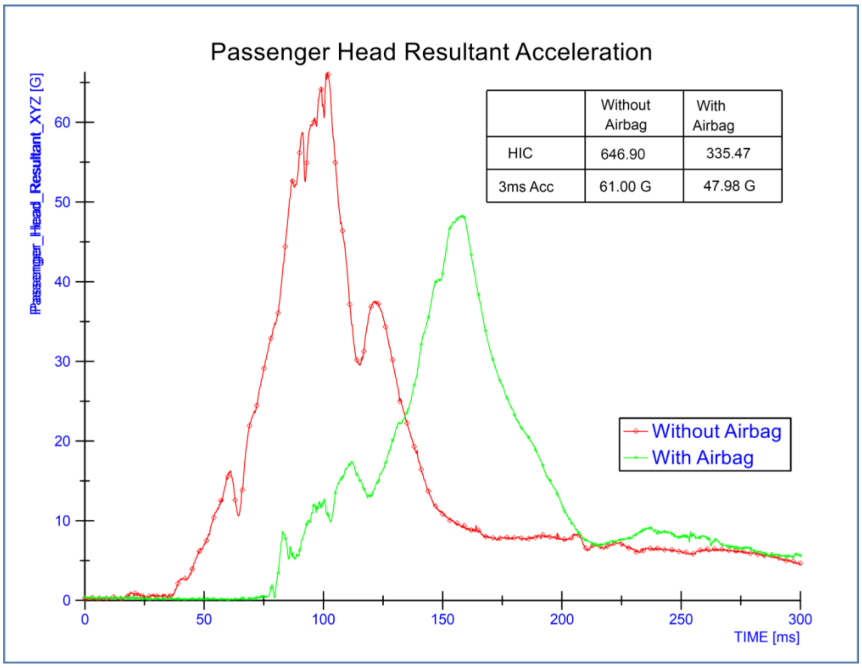

Figure 4: Passenger head resultant acceleration

3.3 Chest Injury Comparison

Another critical region in the human body is the chest. Peak acceleration and maximum deflection (compression) can provide prediction of injury to the human chest. Acceleration was measured through the accelerometer installed inside the chest. The deflection was measured through the potentiometer in the dummy.

Table 1 highlights the driver chest injury data for both cases, i.e. the variants with and without airbag. Chest acceleration was recorded at 59.56 G for the vehicle without airbag while the vehicle with airbag recorded chest acceleration at 40.66 G. Maximum chest deflection for the former was 52.01 mm while the latter had maximum chest deflection of 26.36mm.

The front passenger chest injuries data are presented in Table 2. For the variant without airbag, the passenger's chest suffered 3ms peak acceleration at 39.33 G. With airbag, 3ms peak chest acceleration was recorded at 29.88 G. Maximum chest deflection without airbag installed was at 34.49 mm. For the vehicle that came with airbag, the maximum chest deflection was at 26.36 mm.

The limit for ASEAN NCAP ODB 64 frontal crash has been set at 50 mm chest deflection (ASEAN NCAP, 2015). This analysis indicates for chest loading correspond to 40 to 50% risk of AIS $\geq$ 3 thoracic injury (Harold et al., 1991). In the case of the vehicle without airbag, maximum chest deflection for the driver exceeded the limit by 2 mm. As for the passenger, the maximum chest deflection for both vehicles was within limit. However, there was an improvement with the airbag installed in the vehicle.

Table 1: Driver chest injuries

Injury criterion	Without airbag	With airbag
3ms acceleration	59.56 G	40.66 G
Maximum chest deflection	52.01 mm	26.63 mm

Table 2: Front passenger chest injuries

Injury criterion	Without airbag	With airbag
3ms acceleration	39.33 G	29.88 G
Maximum chest deflection	34.49 mm	26.36 mm

4.0 CONCLUSION

The aim of this paper is to identify the improvement provided by airbag system with the vehicle structure already designed to absorbed energy from the crash. The result for both head and chest injuries show that driver airbag can significantly improve occupant safety. Driver head and chest injuries suffered in the variant without the airbag went beyond the acceptance limit. As for the front passenger, the injuries suffered in the variant without airbag ─ although was within the injury limit ─ were higher compared to the vehicle with the airbag.

Therefore, the airbag system is a very important supplemental system although the vehicle structure has been designed to absorb crash energy. In the head region on the driver's side, the HIC has been improved by 87% while the 3ms acceleration has been improved by 66%. As for the front passenger, HIC and 3ms acceleration were reduced by 48% and 21% respectively.

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