INTERNATIONAL JOURNAL OF AUTOMOTIVE AND MECHANICAL ENGINEERING (IJAME)
ISSN: 2229-8649 e-ISSN: 2180-1606
VOL. XX, ISSUE XX, XXX – XXX
DOI: https://doi.org/10.15282/ijame.v#i#.###

Universiti Malaysia PAHANG

ORIGINAL ARTICLE

Rider's Head Injury Risks in Relation to Motorcycle Designs in Side Crashes with Car

Zulhaidi Mohd Jawi[1,3], Tan Kean Sheng[1*], Dian Darina Indah Daruis[1], Saiddi Ali Firdaus Mohamed Ishak[1], Ng Choy Peng[2]

[1]Department of Mechanical Engineering, Faculty of Engineering, Universiti Pertahanan Nasional Malaysia, Kem Sungai Besi, 57000 Kuala Lumpur, Malaysia
[2]Department of Civil Engineering, Faculty of Engineering, Universiti Pertahanan Nasional Malaysia, Kem Sungai Besi, 57000 Kuala Lumpur, Malaysia
[3]Vehicle Safety and Biomechanics Research Centre, Malaysian Institute of Road Safety Research, Taman Kajang Sentral, 43000 Selangor, Malaysia

ABSTRACT – Motorcycle offers so many advantages as a motorized transport but the risks on the road had translated into a very high number of casualties especially in the ASEAN region. Safety rating program is one the interventions that is hoped to elevate safety level though it faces the economical challenges to embed more technologies and design changes among entry level motorcycles. Thus, this study explores whether or not different motorcycle designs can produce a better crashworthiness advantage to the rider in the event of road crash. Specific to motorcycle versus car crash scenario where a motorcycle impacting a car laterally, this study considered eigth design configurations involving variation of the location of engine block, and the location and orientation of air filter casing. Head resultant acceleration and Head Injury Criteria based on 15 ms time interval (HIC15) is used as response variable to evaluate the injury results. The findings showed that with proper designed layout of the engine block and air filter casing, both the head resultant acceleration and HIC15 can be reduced up to 20% and 47% respectively, compared to the existing motorcycle design.

ARTICLE HISTORY
Received: xxxx
Revised: xxxx
Accepted: xxxx
Published: xxxx

KEYWORDS
Motorcycle Safety
Safety Program
Rider Injury
Motorcycle Simulation

1.0 INTRODUCTION

Producing cars with more motorcycle-friendly features is particularly important in the context of the Southeast Asian region (also referred to as the ASEAN region), where motorcyclists account for more than 90% of all road users (ASEAN Statistics Division, 2020). The mixed traffic scenario creates a high risk of crashes, especially in the context of motorcycle-passenger car collisions, and with notably high fatality rates. In the local context, pre- and post-pandemic road casualty data shows that motorcyclists are still the majority involved in fatal crashes (Figure 1) (MOT, 2023).

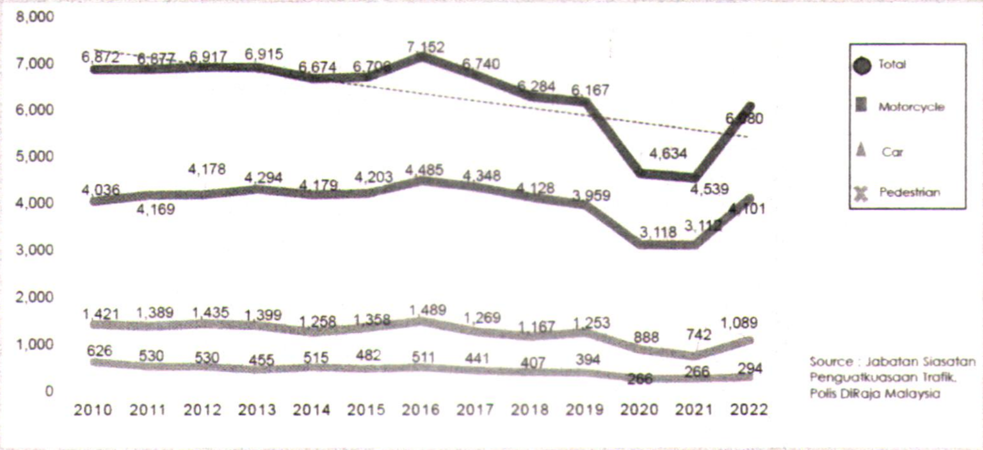


Figure 1. Malaysia's road fatalities 2010-2022 (MOT, 2023)

The main safety perspective of motorcycles is about handling and stability, where this gyroscopic challenge is so much different compared to the stability of vehicles with four or more wheelers (Panzani et al., 2021). Also, in general, a motorcycle is built without the "shell" to provide some sort of outer protection to the riders; therefore, motorcyclists share the same risks as bicyclists and pedestrians (Solagberu et al., 2006; Vaa, 2016). Thus, it is of utmost importance to ensure that motorcycles don't lose balance and fall before the focus is moved to the more tricky topic of motorcycle crashworthiness and motorcyclists' injury protection.

*CORRESPONDING AUTHOR | K. S. Tan | ✉ keansheng@upnm.edu.my

1.1 *Safety Program for Promoting Technology Adoption*

Vehicle safety assessment program has a long and proven history of boosting the adoption of safety technologies in vehicles (Haley & Case, 2001; Wani et al., 2001; Van Ratingen et al., 2016). While human factors especially riding and driving behaviors are already known as the main contributing factors to road crashes, we cannot deny the importance of embedding safety technologies to overcome human weaknesses (mainly active safety), and also to mitigate the risk of injuries during a crash (passive safety). Thus, vehicle safety programs will help to accelerate and democratize safety technologies by balancing the demand and price (economy of scale) and evaluating functional performances (Paine et al., 2015; Abu Kassim et al., 2018).

The New Car Assessment Program or NCAP started in the United States, and other countries and regions adopted a similar approach to ensure only safer vehicles entering the market. Nevertheless, NCAP will take some time to ensure a progressive move to embed the latest safety technologies. For example, ASEAN NCAP keeps renewing its rating regime and testing protocols through the "adopt-adapt" approach to addressing ASEAN problems. Thus, the Motorcyclist Safety Pillar has been incorporated as one of the four primary pillars of the ASEAN NCAP protocol beginning in 2021, as part of ASEAN NCAP's ongoing strategic efforts to reduce the number of incidents and injuries affecting motorcyclists in the view from passenger cars (Abu Kassim et al., 2018; Teoh, 2018). The assessment will cover several technologies such as Blind Spot Detection (BSD), Blind Spot Visualization (BSV), Advanced Rear View Mirror (AVRM), Auto High Beam (AHB), and other technologies under the Advanced Motorcyclist Safety Technology (AMST) (Khalid et al., 2021). These are the active countermeasures to avoid a crash, on top of a set of crashworthiness evaluations to reduce driver and passenger injuries.

The Malaysian Institute of Road Safety Research (MIROS), which is responsible for the development and execution of ASEAN NCAP, later introduced the motorcycle-specific star-rating program called the Malaysia Motorcycle Assessment Program (MyMAP) in 2021 (Zulkipli et al., 2021). This program is in collaboration with another Malaysian government agency, i.e., the Malaysia Automotive, Robotics, and IoT Institute (MARii). MyMAP program, which can be regarded as the first in the world (Carroll et al., 2022), is directly assessing the quality of motorcycle models entering the market. However, as questioned by Carroll et al. (2022), the program at this stage did not embed a direct crashworthiness evaluation (Amir et al., 2021). Nevertheless, MyMAP is seen as a potential safety accelerator to complement the ASEAN NCAP movement to protect motorcycle users from a car's perspective.

1.2 *Passive Safety for Motorcycles*

Passive safety features have primarily focused on the motorcycle-rider system, such as motorcycle airbags (Aikyo et al., 2015), airbag jackets (Serre et al., 2019; Zhang et al., 2023), and head-and-neck protective devices (Gobbi et al., 2019). To design these efficient passive safety measures, a thorough study of the behaviors of the motorcycle and rider as they interact with the opposing vehicle during crashes is essential. There has been a significant deal of research into the kinematics of motorcycles and riders, as well as the distributions and processes of injuries in crashes (Chinn et al., 2001; Toma et al., 2010; Serre et al., 2012; Carmai et al., 2019). The majority of such studies focused on frontal, or Type I crashes, in which a motorcycle collided directly with another vehicle, which is widely recognized as the most serious sort of road crash. Such collisions are not only highly represented in statistics (Whitaker, 1980; Otte et al., 1981; Harms, 1989; Pang et al., 2000; Piantini et al., 2016), but they also always result in serious or fatal head injuries (Sporner et al., 1990; Pang et al., 1999; Piantini et al., 2016), as the rider is frequently ejected from the motorcycle and thrown directly towards the opponent vehicle, with the head directly impacting with stiff parts of the opponent vehicle.

While there was a considerable number of studies looked at the influences of vehicle front-end design on injury outcomes of pedestrians (e.g., Han et al., 2012; Li et al., 2017) and bicyclists (e.g., Fanta et al., 2013; Bourdet et al., 2014), not much of similar focus given to motorcycle impact scenario. Schaper and Grandel (1985) analyzed the rider's interaction with the motorcycle fuel tank and handlebar, and head impact on the car in motorcycle-car impact tests, and the results showed high head impact load was observed when the car's structural parts were hit. On the other hand, Xiao et al. (2020) presented an investigation into the influences of impact scenarios and vehicle front-end design parameters on the rider's head injury risk. The front-end designs varied by bonnet design such as its length, height, angle, and windshield angle, where the variations were found to highly influence rider's head injury risks during motorcycle-vehicle impacts. To add another perspective, design changes such as decreasing the bonnet angle and increasing length can lessen the head injury risks. Nonetheless, there is also a lack of studies that concentrate on how a rider's head injury is associated with the dynamics of a motorcycle in frontal impact.

The bigger vision of the authors' effort in this research is to explore the potential of motorcycle design variation that can contribute to the crashworthiness of a motorcycle, i.e., lessening the injury level sustained in an impact. This will in turn provide some insights into any safety movement or rating program such as NCAP or MyMAP. Specific to this study, it was hypothesized that different designs of motorcycle's frontal parts will affect the dynamics in crashes and reduce injury risks. The first specific objective of the study is to explore the feasibility of performing modifications to the bike layout design. Then, the second specific objective is to investigate the effects of motorcycle dynamics on the rider's head injury based on 15 ms interval of Head Injury Criteria widely known as HIC15.

2.0 METHODS AND MATERIAL

This section will describe the simulation model setup and experimental design in this study. The present study utilized finite element simulation as the tool to realize the motorcycle layout modifications. The motorcycle model used is based on one of the Malaysian national producers's models, i.e. the early version of MODENAS Kriss 110 (Shahril et al., 2013).

2.1 Simulation Model Setup

The Kriss 110 model represents the most common motorcycle type that is widely used in the country as well as in the ASEAN region, i.e. the underbone type. To add another perspective, the second most popular design is the scooter type. The underbone motorcycle is typically characterized by an engine capacity of 125±25 cc, mass of 100±10 kg, and wheelbase of 1250±50 mm. Other popular models in Malaysia are the Honda EX5, Yamaha 135LC, Suzuki Smash, etc.

In real-world frontal crashes, the motorcycle's wheel and fork assemblies often experience significant deformations (Pang, 2000; Hamzah et al., 2014; Arrifin et al., 2016). Moreover, these frontal structures had already severely deformed even before the rider (or the dummy from an experimental perspective) began to experience significant forward movement (Ariffin et al., 2016). Furthermore, it was demonstrated that the dynamics of the motorcycle and dummy rider in frontal crashes were dependent on the initial collapsing characteristics of the front wheel (Yettram et al., 1994), which could influence the initial pitching dynamics and, as a result, the rider's behavior. Thus, to accurately portray the dynamics of a motorcycle, these structures must be simulated in depth. The level of modeling detail was determined by findings from crash tests (Arrifin et al., 2016; Hamzah et al., 2014), as well as component test results (Tan et al., 2006, 2008). The wheel model incorporated an air-inflated tire and wire-spoked wheel assembly, while the fork assembly was modeled with suspension capability, as illustrated in Figure 2. The detailed modeling and validation aspects of these critical frontal structures are respectively available in (Tan et al., 2013, 2016a, 2016b).

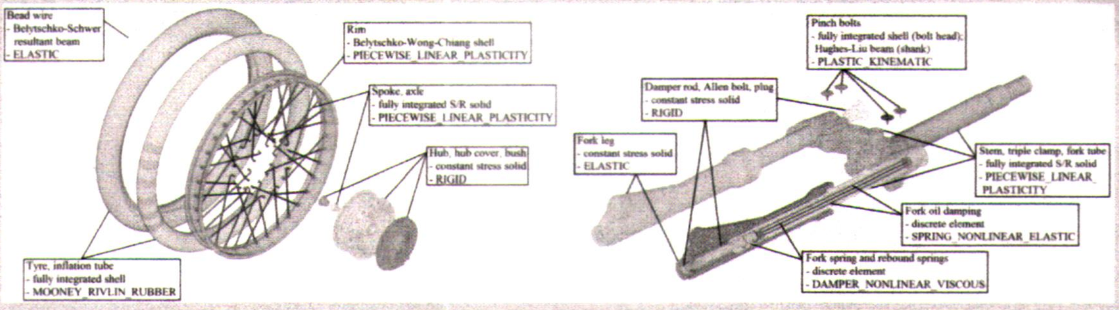


Figure 2. Finite element models of wheel and fork assemblies.

The motorcycle model used was validated by evaluating the kinematics of the motorcycle against physical test data of frontal impact with a moving rigid barrier, using the Roadside Safety Verification and Validation Program (RSVVP) 20 (Mongiardini & Ray, 2009). Comparisons of the time histories are shown in Figure 3 whilst the evaluation metrics and also the outcomes are summarised in Table 1.

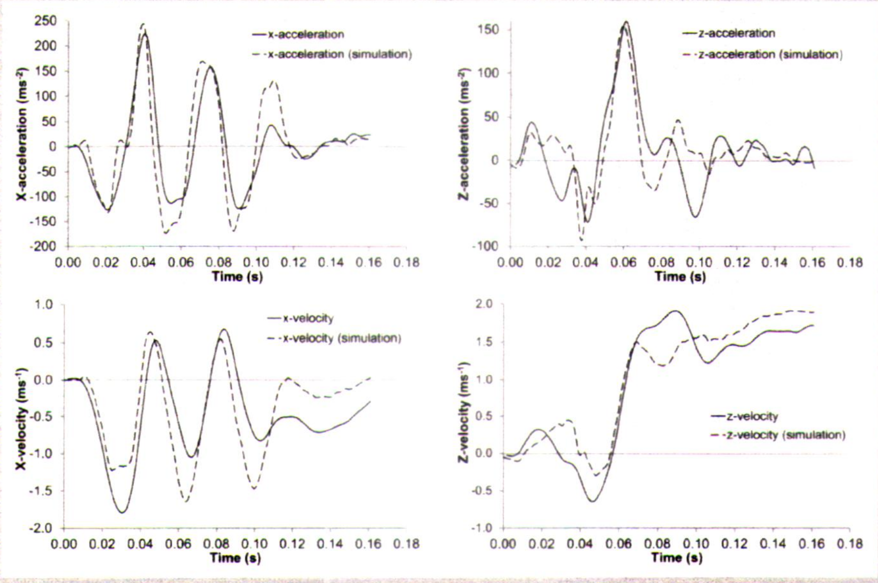


Figure 3. Evaluation of acceleration and velocity profiles between the simulation and the physical test.

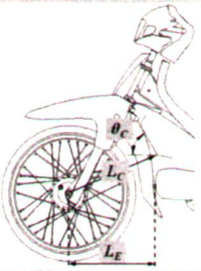
Table 1. Validation outcomes of the motorcycle model using RSVVP.

Response	Metrics (Acceptance limit)				
	Sprague-Geers MPC			ANOVA	
	Magnitude (40%)	Phase (40%)	Comprehensive (40%)	Average (5%)	Standard Deviation (35%)
x-acceleration	17.6	16.5	24.2	0.9	21.6
z-acceleration	-11	22.7	25.2	0.8	19.8
x-velocity	-3.5	19.7	20	4.3	24.2
z-velocity	1.9	7.5	7.7	4.4	14.9

For the current feasibility and exploratory nature of the study, a simpler version of LSTC Hybrid III 50th Fast Dummy (Guha et al., 2011) was used to represent the rider. No helmet was fitted to the dummy considering that the main analysis will be on the relative head injury risks among different designs of the motorcycle layout, and therefore there is a need to exclude any cushioning and protective effect from the helmet and to assess the absolute head injury levels.

2.2 Experimental Design

Figure 4 depicts the factors and their corresponding level settings that were applied in 2^3 factorial design for the purpose of parametric study in designing the combination of factors. The factors are the engine location (L_E), the air filter casing location (L_C), and its orientation (θ_C). The L_E and L_C are measured from the axle, while θ_C is measured from the horizontal axis. The plus and minus signs represent the high and low levels of the related factors. The likelihood of adjusting the factors' levels was rather limited due to the confined space around the engine block and air filter casing. Therefore, only two levels were considered in the current study for each factor. The original configuration of both the engine and casing was set as the low levels for the corresponding factors. A two-level 2^3 factorial design produced eight different factorial treatments. The visualization of each of the combinations of the factors is illustrated in Figure 5, of which the motorcycle model was modified accordingly and fitted with a dummy rider. The individual motorcycle-rider models was then used to simulate a direct frontal crash into a Toyota Yaris passenger car (Marzougui et al., 2012), with the impact location at the midspan of the driver-side door, at an impact velocity of 11.11 ms^{-1} (40 km/h). The simulated impact velocity was set based on the value of median crash speed reported in on-scene, in-depth studies of motorcycle road accidents (Kasantikul, 2002a, 2002b). The chosen response variable fo injury severity assessment was head resultant acceleration and HIC15.



Factor	Notation	Factor level	
		Low (-)	High (+)
Engine location (m)	L_E	0.357	0.397
Air filter casing location (m)	L_C	0.391	0.437
Air filter casing orientation (radian)	θ_C	1.117	1.571

Figure 4. Definition of design factors.

Figure 5. Visualization of motorcycle layout based on 2^3 factorial design.

3.0 RESULTS AND DISCUSSION

3.1 Motorcycle kinematics

To facilitate discussion, the simulated crash scenario of Design 1 is to be used as a representative example, since the behaviors for other configurations were found to be qualitatively almost similar to each other. The overall behavior of the motorcycle and rider of Design 1 is illustrated in Figure 6, from the initial contact between the motorcycle tyre and the sill of the opponent vehicle until the moment the rider's head impacts the top edge of the window frame/roof side rail. Here, Indeed, as shown in Figure 7, the acceleration and velocity time histories of the motorcycle (with reference to centre of gravity (CG)) during crashes also show the similar trends, with some differences in terms of peak magnitudes and the corresponding peaking moments. The time histories of the motorcycle kinematics of the Design 1 as presented in Figure 8 indicate the key incidents during the crash. The *y*- and *z*- prefixes represent the horizontal and vertical components, respectively, with the leftward and upward being the positive directions. The moment when the front tyre almost contacts the sill is considered as time zero.

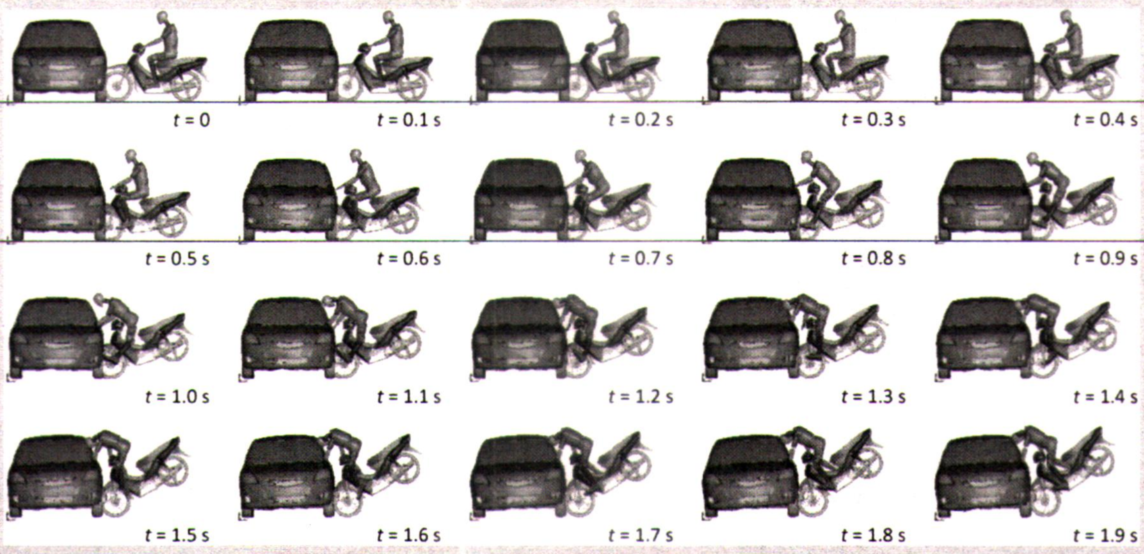
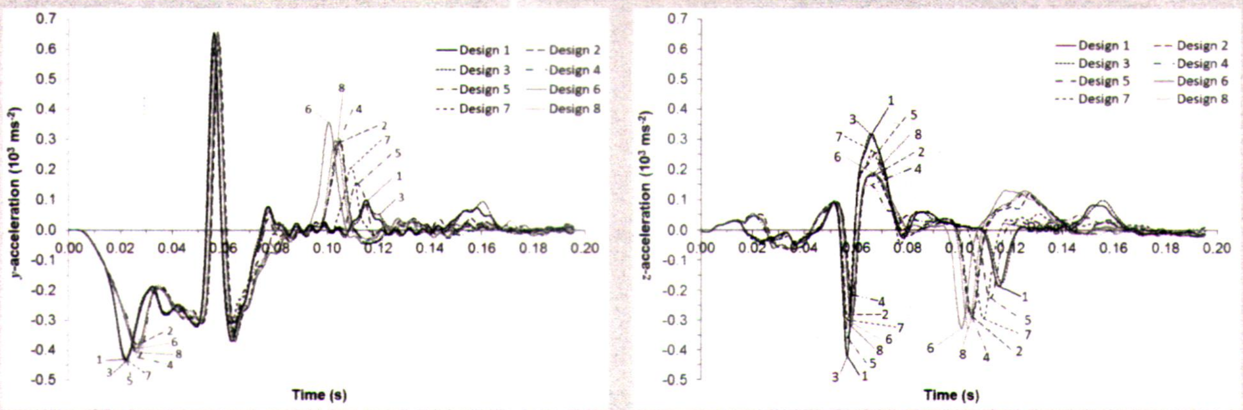


Figure 6. Typical behavior of the motorcycle-rider system (Design 1).



(a) (b)

Figure 7. Motorcycle time histories of the individual designs in crash simulations: (a) horizontal acceleration; (b) vertical acceleration. (Leftward and upward are positive.)

When the fork tube started to bend at about 0.002 s, the motorcycle started to experience significant horizontal deceleration as indicated by the suddent drop in the *y*-acceleration curve that accompanied with the dropping of positive velocity.The deceleration reaches the peak magnitude at 0.021 s when the tyre gets fully compresses against the forward face of the engine block. The bent rim eventually contacted the hub and the wheel reached maximum deformation, signifies the maximum engagement of the wheel with the sill, at about 0.05 s. During the rim localized deformation stage, the fork retracted and the motorcycle front end experienced diving as denoted by the negative *y*-velocity accompanying with negative *z*-acceleration. Some slight fluctuations that occur in vertical accelerations are mainly due to interactions between the diving and pitching motions and the deformations of the wheel and front fork assemblies. The diving of the front end does allowing for some small horizontal motion while the fork springs are being compressed. This duration is signified by a lower rate of horizontal deceleration approaching 0.053 s until the *y*-velocity reaching the zero. The increasing rate of vertical velocity also gradually reduced as the resistance of fork spring increases due to increasing diving amount.

This is followed by the knees hitting the fenders, at 0.054 s, intensifying the forward diving motion and causing the sharp increasing in positive (forward) *y*-acceleration and negative (downward) *z*-acceleration immediately, accompanied by the corresponding increasing positive *y*-velocity and negative *z*-velocity, signifying the accelerating motions. These two accelerations reached the respective peak values at 0.056 s. The kneeds separated from the fenders at 0.063 s, where the deceleration rate dropped because the pitching effect produced by the knees impact is diminishing. Eventually the motion changes direction at 0.067 s where the CG started to move rearward. The fluctuation of the *y*-acceleration from 0.08 s to 0.11 s was due to the horizontal motion of the motorcycle through backward wheel rolling, recovery from diving from decompression of fork springs, and the rearward swinging motion of the motorcycle body.

The maximum compression of the fork also occurred at 0.067 s, followed by some further compression at the bottom of the tyre and the rim, and finally reach maximum engagement at about 0.07 s. The vertical motion was slowing down as the maximum fork compression is approached due to the gradually increasing resistance of the fork spring. Eventually it reached the compression limit, the doward velocity started to turn to upward one, as seen by the vertical velocity curve crosses *x*-axis and enter positive one at 0.067 s, afterwhich the vertical rebound start to take place. The velocities then gradually becoming constant when it move freely as external disturbances such as the fork spring force diminished. Some fluctuations were observed when the dummy come into contact with the motorcycle.

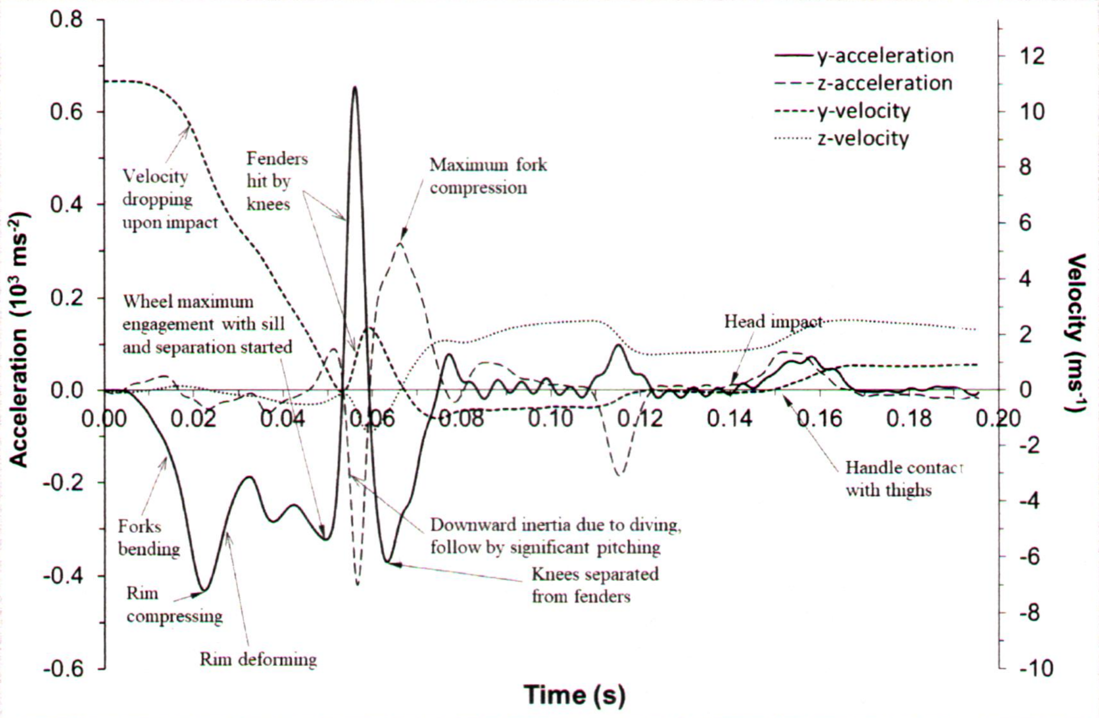


Figure 8. Charateristics of motorcycle kinematics in a crash.

3.2 *Rider's behaviours*

The rider's behaviour with reference to the H-point is presented in Figure 9. After the motorcycle impacted the car and experienced deceleration, the rider that having the same initial velocity with the motorcycle, started to slide forward along the seat at a rather constant velocity but shows a gradual and small drops under a mild deceleration. The motion is accompanied by some gradual increase in the vertical velocity that due to the force exerted by the seat on the rider's buttocks when the front end dives and the motorcycle pitches. This force also affected the horizontal component, where a slight increase in the curve is noticeable right before the sudden drop of the *y*-velocity. It is worthwile to note that the rider's sliding motion became apparent only after 0.02 seconds after the initial contact, which is the time the first maximum deceleration occurred. This observation is consistent with high-speed video clips of a full motorcycle crash test (Arrifin et al., 2013; Hamzah et al., 2014).

When the knees contacted the fenders, at about 0.053 s, the obstructed motion caused the sudden drop in *y*-velocity with abrupt deceleration with relatively high peak magnitude. The pitching of the motorcycle that follows immediately after the knees impact on the fenders subsequently brought the seat to impact the buttocks at about 0.06 s, and thus provides the forward and upward momentum to the rider. The effect is significant for vertical component, where the curve rises significantly after the buttocks impact. Whereas for *y*-velocity, the decreasing rate of velocity is also reduced. The contact last until about 0.063 s when the knees started to separate from the fenders. The rider then fully airborne and progressively came into contact with the opponent vehicle parts, first through the hands of which the interaction interferes with the rider's motion and therefore the *y*-velocity is seen fluctuating about the time axis (Figure 9). Eventually at about 0.14 s, the rider's head came into impact with the opponent vehicle, at the top edge of window frame and/or roof.

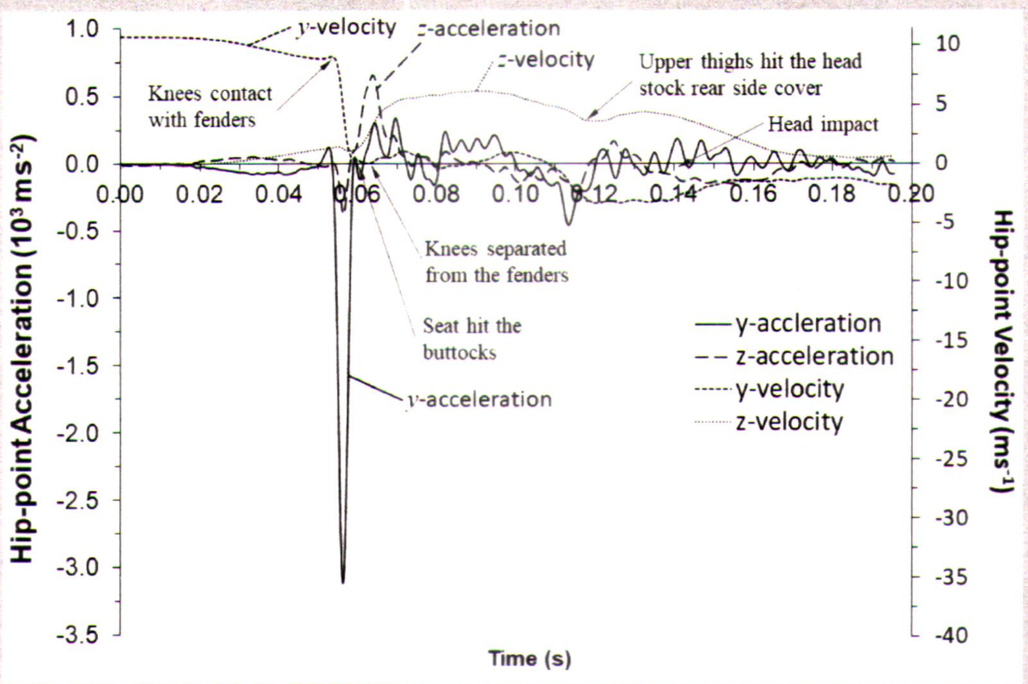


Figure 9. Hip-point kinematics during the crash.

3.2 Head responses and injury risks

The individual filtered time histories of the rider's head resultant acceleration during the impact with the opponent car, are shown in Figure 10, for the corresponding different motorcycle designs. Generally, the acceleration curves started to rise rapidly to peak values as the head came into contact with the struck part with the average duration ranging from 0.01 s to 0.02 s. The individual peak head resultant acceleration magnitudes and HIC15 scores are summarized in Table 2. It is worthwhile to note before moving on to the next discussion that the curve cluster from design 6 is the only one that is missing the peak. This is because, unlike in other designs, the rider's head struck the door window which occurred at a later time at 0.16 s and break through it, rather than hitting the top edge of the window frame or the roof. Since the struck object are structural significantly different, it is not comparable to others for comparing the impact severity because the impact condition is different and thus is excluded in the current study.

Peak head resultant acceleration varies between 5% and -20% when compared to Design 1, with Design 5 having the highest peak acceleration and Designs 3 and 7 having the lowest. For HIC15, the range is from -47% to 7%, correspoding to Designs 2 and 3, respectively. It was found that the order of head resultant acceleration magnitude has no direct correlation with the order of HIC15 score, because the score accounts for the acceleration duration. With the consecutive two peaks that follows immediately one and another, for example in the design 8, the duration is almost double of that of design 2 and the HIC15 is significantly higher than design 2 though the peak magnitude is lower. The injury severity outcome in terms of HIC15 is different when compared to the condition of direct frontal impact with rigid wall (Jawi et al., 2021), of which the most severe cases are of designs 2 and 4, respectively. This somehow indicated that during the impact, there was a certain interaction between the response of the opponent vehicle parts such as the door and window frame and the deformation of the motorcycle front end structural parts.

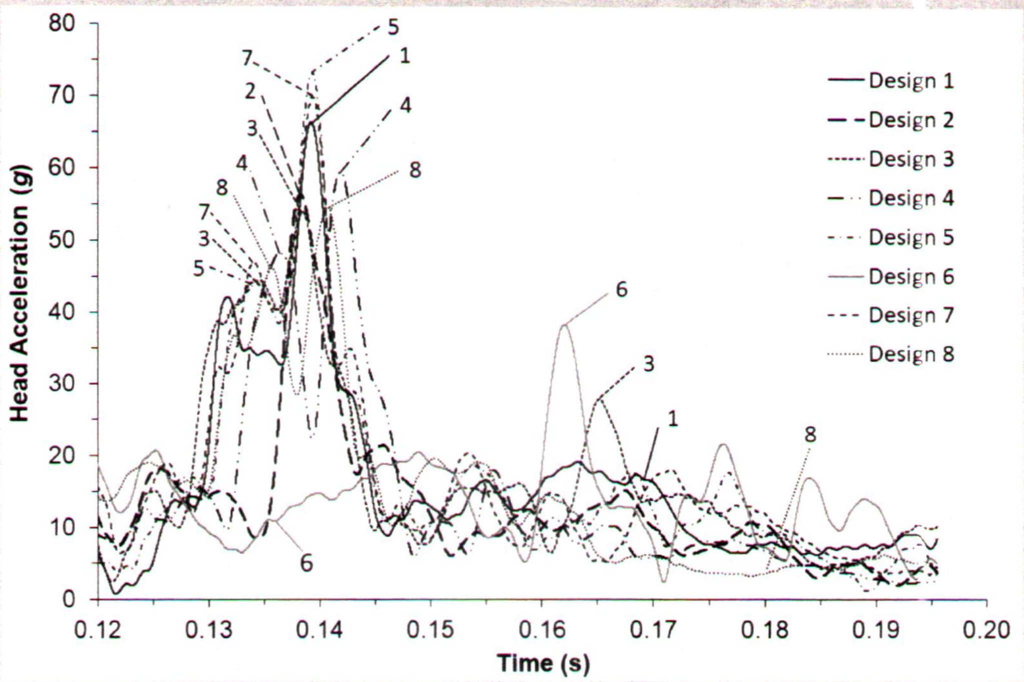


Figure 10. Time histories of head acceleration during head impact measured in gravitational acceleration (g).

Table 2. Head response and injury risk corresponsing to each design.

		Design							
		1	2	3	4	5	6	7	8
Factor	L_E	–	+	–	+	–	+	–	+
	L_C	–	–	+	+	–	–	+	+
	θ_C	–	–	–	–	+	+	+	+
Response	Head peak resultant accceleration (g)	67	56	54	59	73	38	70	54
	HIC15	135	**71**	144	134	166	23	167	119
	Normalized (against Design 1)	1.00	**0.53**	1.07	0.99	1.23	0.17	1.24	0.88

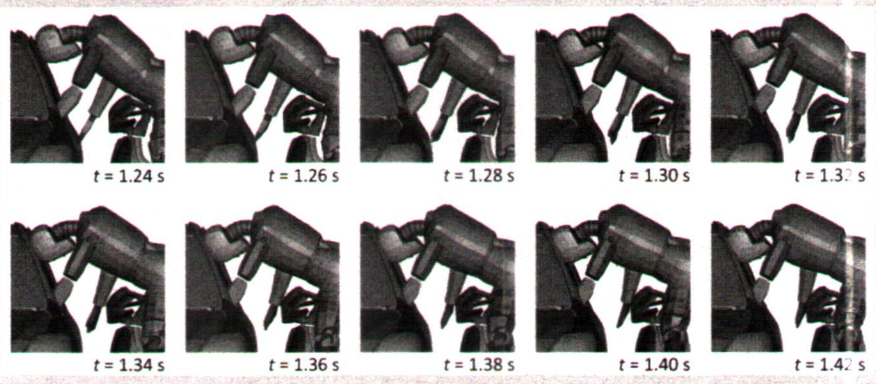


Figure 11. Head impact on a top edge of the window frame followed by the second contact with the roof side rail.

The two designs that yield corresponding 47% and 12% reduction in HIC15 score, i.e. Designs 2 and 8, have engine location (L_E) set at high level where it is horizontally located 40 mm farther away from the front axle compared to the original Design 1. This provide more room for the fork to bend which allow for more gradual increases of deceleration before reaching the peak magnitude.

There are two key stages in the kinematics of the motorcycle that affect the rider's behaviour. The first one is the first horizontal deceleration experienced by the motorcycle leading to the first negative peak magnitude (Figure 7a) at about 0.02 s to 0.03 s, in which Design 2 showed a much lower deceleration rate and experienced 11% lower of peak magnitude, and the pelvic horizontal resultant 10% lower. The second stage is during the incident of knees hitting the fenders, in which the induced vertical acceleration from motorcycle pitching then caused the seat to hit the rider's buttocks, which in turn exerted greater ejection momentum to the rider. Compared to the Design 1, Design 2 motorcycle has a reduction of 32% in motorcycle vertical deceleration whilst the pelvis vertical deceleration reduced for 22%.

4.0 CONCLUSIONS

This study explores the potential of altered designs of motorcycle's frontal parts will affect the dynamics in crashes and reduce injury risks with the bigger vision being to promote crashworthiness improvement in motorcycles entering the market. Based on the simulation results, two designs were found to be able to reduce significantly head injury risk in terms of HIC15, i.e. for about 47% and 12%. This was accomplished by simply changing the placement of engine block and air filter casing to allow for the most gradual deformations of the front wheel and fork. Such design modifications are considered viable and practicable because it does not require major design changes on the structural components of motorcycle to the extend such as redesigning front fork or changing material of the rim and spokes. Knowledge has also been gained on how structural response of the frontal structures of motorcycle could be taken into account as part of design elements in reducing rider's head injury risks in frontal crashes. More comprehensive crash configurations needs to be covered in order to gain more generalized relationship between the rider's HIC15 score and the motorcycle kinematics.

5.0 CONFLICT OF INTEREST

The authors declare no conflicts of interest.

6.0 AUTHORS CONTRIBUTION

Z.M. Jawi (Conceptualization; Formal analysis; Visualisation; Supervision)

K.S. Tan (Methodology; Data curation; Writing - original draft; Resources)

D.D.I. Daruis (Setup of dummy model and injury analysis)

S.A.F. Mohamed Ishak (Kinematic analysis of the motorcycle-rider system)

C.P. Ng (Statistical analysis)

7.0 ACKNOWLEDGEMENTS

The authors would like to thank the management of the UPNM's Faculty of Engineering for their support. This study was not supported by any grants from funding bodies in the public, private, or not-for-profit sectors.

8.0 REFERENCES

[1] ASEAN Statistics Division. (2020). Total number of registered motorcycles (in thousand), Retrieved from https://data.aseanstats.org/indicator/ASE.TRP.ROD.B.011

[2] MOT (2023). Malaysia Road Safety Plan 2022-2030. Ministry of Transport Malaysia.

[3] Panzani, G., Todeschini, D., Corno, M., Sette, D., & Savaresi, S. M. (2021). Co-design and experimental validation of a gyroscopic stabilizer for powered two-wheelers. IEEE/ASME Transactions on Mechatronics, 27(5), 2484-2494.

[4] Solagberu, B. A., Ofoegbu, C. K. P., Nasir, A. A., Ogundipe, O. K., Adekanye, A. O., & Abdur-Rahman, L. O. (2006). Motorcycle injuries in a developing country and the vulnerability of riders, passengers, and pedestrians. Injury Prevention, 12(4), 266-268.

[5] Vaa, T. (2016). ITS and the effects on vulnerable road users: the case of motorcyclists. In 17th International Conference Road Safety On Five Continents (RS5C 2016), Rio de Janeiro, Brazil, 17-19 May 2016 (pp. 1-6).

[6] Haley, J., & Case, M. (2001). Review of Australian NCAP since ESV 1998 (No. 2001-06-0213). SAE Technical Paper.

[7] Wani, K., Ohta, S., & Ishikawa, H. (2001). J-NCAP: Today and tomorrow (No. 2001-06-0157). SAE Technical Paper.

[8] Van Ratingen, M., Williams, A., Anders, L., et al. (2016). The European New Car Assessment Programme: A historical review. Chinese Journal of Traumatology, 19(02), 63-69.

[9] Abu Kassim, K. A., Abidin, A. N. S. Z., Faudzi, S. A. M., Zulkipli, Z. H., Jawi, Z. M., & Ahmad, Y. (2018). MIROS's role in establishing the Electronic Stability Control (ESC) regulation in Malaysia. Journal of Science & Technology (JSET), 4(02).

[10] Paine, M., Paine, D., Smith, J., Case, M., Haley, J., & Worden, S. (2015). Vehicle safety trends and the influence of NCAP safety ratings. ESC, 20(41), 85.

[11] Abu Kassim, K.A., Ahmad, Y., Mustaffa, S., & Mansor, M.R.A. (Eds.) (2018). ASEAN NCAP Road Map 2021-2025. Selangor: New Car Assessment Program for Southeast Asian Countries.

[12] Teoh, E. R. (2018). Motorcycle crashes potentially preventable by three crash avoidance technologies on passenger vehicles. Traffic Injury Prevention, 19(5), 513-517.

[13] Khalid, M. S. A., Zulkipli, Z. H., Solah, M. S., Hamzah, A., Ariffin, A. H., Amir, A. S., ... & Khamis, N. K. (2021). A review of motorcycle safety technologies from the motorcycle and passenger car perspectives. Journal of the Society of Automotive Engineers Malaysia, 5(3), 417-429.

[14] Zulkipli, Z.H., Alias, N. K., Omar, A., et al. (2021). MyMAP: World's first holistic rating system for motorcycles. Journal of the Society of Automotive Engineers Malaysia, 5(3), 408-416.

[15] Carroll, J., Gidion, F., Rizzi, M., & Lubbe, N. (2022). Do motorcyclist injuries depend on motorcycle and crash types? An analysis based on the German In-Depth Accident Study. In International Motorcycle Conference (IFZ).

[16] Amir, A. S., Zulkipli, Z. H., Alias, N. K., Omar, A., Kak, D. W., Mahmud, M. N., ... & Kassim, K. A. (2021). Elemen pendidikan pemandu di dalam program penarafan keselamatan motosikal. iLEARNed, 2(2).

[17] Aikyo, Y., Kobayashi, Y., Akashi, T., & Ishiwatari, M. (2015). Feasibility study of airbag concept applicable to motorcycles without sufficient reaction structure. Traffic Injury Prevention, 16(sup1), S148-S152.

[18] Serre, T., Masson, C., Perrin, C., Martin, J. L., Moskal, A., & Llari, M. (2012). The motorcyclist impact against a light vehicle: Epidemiological, accidentological and biomechanic analysis. Accident Analysis & Prevention, 49, 223-228.

[19] Chinn, B.P., Canaple, B., Derler, S., Doyle, D., Otte, D., Schuller, E., & Willinger, R. (2001). COST 327 Motorcycle Safety Helmets - Final report of the action. Retrieved from https://ec.europa.eu/transport

[20] Toma, M., Njilie, F.E.A., Ghajari, M., & Galvanetto, U. (2010). Assessing motorcycle crash related head injuries using finite element simulations. International Journal of Simulation Modelling, 9(3), 143–151.

[21] Serre, T., Masson, C., Perrin, C., Martin, J-L., Moskal, A., & Llari, M. (2012). The motorcyclist impact against a light vehicle: Epidemiological, accidentological and biomechanic analysis. Accident Analysis and Prevention, 49, 223-228.

[22] Carmai, J., Koetniyom, S., & Kassim, K.A.A. (2018). Analysis of rider and child pillion passenger kinematics along with injury mechanisms during motorcycle crash. Traffic Injury Prevention, 20(S1), S13-S20.

[23] Whitaker, J. (1980). Survey of motorcycle accidents. TRRL Laboratory Report LR913, Transport and Road Research Laboratory, Crow Thorne, Berkshire, U.K.

[24] Otte, D., Kalbe, P., & Surgen, E.G. (1981). Typical injuries to the soft body parts and fractures of the motorised 2-wheelers, 1981 IRCOBI Conference Proceedings, 148-165.

[25] Harms, P.L. (1989). Leg injuries and mechanisms in motorcycle accidents. Proceedings of the 12th International Conference on Experimental Safety Vehicles, Gothenburg, May.

[26] Pang, T.Y., Radin Umar, R.S., Azhar, A.A., Megat Ahmad, M.M.H., Nasir, M.T.M., & Harwant, S. (2000). Accident characteristics of injured motorcyclists in Malaysia. Medical Journal of Malaysia, 55(1), 45-50.

[27] Piantini, S., Pierini, M., Delogu, M., Baldanzini, N., Franci, A., Mangini, M., & Peris, A. (2016). Injury analysis of powered two-wheeler versus other-vehicle urban accidents. 2016 IRCOBI Conference Proceedings, 840-853.

[28] Sporner, A., Langwieder, K., and Polauke, J., Passive safety for motorcyclists - from the leg protector to the airbag. SAE International Congress and Exposition, Detroit, February-March 1990.

[29] Pang, T.Y., Radin Umar, R.S., Azhar, A.A., Harwant, S., Wahid, S.A., Mansor, A.H., Noor, Z., & Othman, M.S., (1999). Fatal injuries in Malaysian motorcyclists. International Medical Research Journal, 3(2), 115-119.

[30] Zhang, X., Xue, Z., & Tu, W. (2023). Design and performance research of a wearable airbag for the human body. Applied Sciences, 13(6), 3628.

[31] Gobbi, M., Mastinu, G., & Previati, G. (2019). Motorcycle accidents - A new head and neck safety device for riders. International Journal of Automotive Technology, 20, 25-36.

[32] Han, Y., Yang, J., Nishimoto, K., Mizuno, K., Matsui, Y., Nakane, D., Wanami, S., & Hitosugi, M. (2012). Finite element analysis of kinematic behaviour and injuries to pedestrians in vehicle collisions. International Journal of Crashworthiness, 17(2), 141–152.

[33] Li, G., Lyons, M., Wang, B., Yang, J., Otte, D., & Simms, C. (2017). The influence of passenger car front shape on pedestrian injury risk observed from German in-depth accident data. Accident Analysis and Prevention, 101(2), 11–21.

[34] Fanta, O., Bouček, J., Hadraba, D., & Jelen K. (2013). Influence of the front part of the vehicle and cyclist's sitting position on the severity of head injury in side collision. Acta of Bioengineering and Biomechanics, 15(1), 105-112.

[35] Bourdet, N., Luttenberger, P., Teibinger, A., Mayer, C., Winllinger, R. (2014). Pedestrian and bicyclists head impact conditions against small electric vehicle. 2014 IRCOBI Conference Proceedings, 685-696.

[36] Schaper, D., & Grandel, J. (1985). Motorcycle collisions with passenger cars: analysis of impact mechanism, kinematics, and effectiveness of full face safety helmets. SAE Transactions, 94, Section 1, 544-551.

[37] Xiao, Z., Wang, L., Mo, FH., Lv, XJ., & Yang, CH. (2020). Influences of impact scenarios and vehicle front-end design on head injury risk of motorcyclist. Accident Analysis and Prevention, 145, 105697.

[38] Shahril, K., Kasim, N.B. ., & Sabri, M. (2013, December). Heat transfer simulation of motorcycle fins under varying velocity using CFD method. In IOP Conference Series: Materials Science and Engineering (Vol. 50, No. 1, p. 012043). IOP Publishing.

[39] Ariffin, A.H., Solah, M.S., Hamzah, A., et al. (2016). Exploratory study on airbag suitability for low engine capacity motorcycles. Jurnal Teknologi, 78(4).