

Design and Development of Universal Pillion Foot-board for Underbone Motorcycle

Ruwaitdy Mat Rasul, Tuty Liana Medali, Sharifah Hanis Yasmin Sayid Abdullah, Azizah Endut

Abstract: This study is carried out to design and develop a pillion foot-board to include safety features specifically for Malaysian two-wheelers drivers and children pillion passengers. This is due to the potential vulnerability of children pillion passengers and the possibility of injuries caused by accidents. Triangulations methodology was applied with observational and survey studies have been conducted in several areas including Johor, Kelantan and Terengganu. The observation technique was conducted to identify the problem of available foot-board design and the design criterion. The interviews were conducted to identify the experience from the users. The school area was found to be the most covered place as most of the pillion passengers were the primary /elementary schools and kindergarten students. Almost 76% of the underbone motorcycle user used motorcycle for the purpose of sending and fetching their children to school every day. It was also found that they have encountered an accident before caused by the unbalanced situation on the road. The design and development of pillion foot-board namely PIJAK involved two stages before the outcome can be finalised. Preliminary design using two-dimensional and three-dimensional design was simulated using CAD software based on the product design criteria. Von Mises Stress analysis was conducted to determine the strength and capacity of the design product. Prototype 3 was found as the best model for PIJAK. The design and fabrication of PIJAK be able to provide a form of protection and comfort to young pillion riders. The product is expected to reduce the risk of children's feet injuries during motorcycle riding.

Keywords: Children, Foot-board, Motorcycle, Pillion, Safety.

I. INTRODUCTION

Road traffic accidents are now becoming more common with the advent of more vehicles on the roads. According to the World Health Organisation (WHO), around 830,000 children are fatally injured from accidental or unintentional injuries every year. Most of these injuries happen in the middle to low-income nations [1]. In Malaysia, transport-related accidents were one of the main causes of death in 2017 for the 0 – 14 and 15 – 40 years old population [2]. Motorcycle related injuries and its resulting fatalities are

increasing at an alarming rate in the developing country. In Asian countries, motorcycle crashes are the leading cause of morbidity and mortality among children [3]. In Malaysia, the problem is largely related to on-road riding with young children commonly injured both as operators and pillion passengers [4,5]. Underbone motorcycles, which are engine capacity ranges from 80 to 150 cc are commonly used and one of the most popular mode of transportation for lower-income group and most families because they are reliable and affordable compared to other forms of motor vehicles [6]. In 2011, of the total 525,091 motorcycles sold, 96 % were had engine capacities lower than 150 cc [7]. As more underbone motorcycles are on the roads, safety concerns increase, including some that are exclusive to the local culture; children pillion. As described by Watson et al. [8], a pillion passenger should be positioned directly behind the rider, facing forward on a registered seat. Motorcycle users and their passengers are vulnerable to injuries because limited or no physical protection is provided by the motorcycle to its users. Children are more susceptible to injuries during an accident when pillion on motorcycles. In a study done by the Malaysian Institute of Road Safety Research (MIROS) and Road Accident Analysis and Database System (MROADS) in 2009, among all types of road users, motorcyclists had the highest annual fatality rate in Malaysia, with the number of deaths as high as 3,600. Children from different age groups who were riding as riders or pillion riders were among these recorded fatalities (19–20%) [9].

Some countries have minimum age restrictions of between five and eight years for passengers of on-road motorcycles. However, there does not appear to be clear evidence for these limits nor many studies of the physical limits to safe travel as a pillion passenger. Young children under the age of twelve will need constant adult care and guidance as they are extremely vulnerable due to them being exposed to possible fatal conditions. It is therefore common to see the safety consideration especially towards the pillion rider is not considered a priority. In a situation where the pillion rider is a child, its normally holds on to the adult rider tightly to balance themselves and avoid falling. According to the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF), children are rarely spotted on the backs of motorcycles in the most developed countries, which is contrary to most Southeast Asian countries where children are often spotted on the backs of motorcycles as pillion riders [3]. In some extreme cases, it is common to see infants are being carried on motorcycles. They are either carried by the rider or another adult passenger where the infants are seated in front of the driver (in a basket or the tank)

Revised Manuscript Received on October 15, 2019

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or multiple between the rider and the adult passenger [10]. According to MIROS, child pillion passengers in the age of 1 to 14-year-old range are the third leading group of traffic-related deaths in Malaysia. [11] Motorcycles constitute the second-highest number of vehicles involved in road accidents every year. Table 1 shows reported child casualties in motorcycle accidents from 2006 to 2008.

Table- I: Motorcycle accident casualties (Children 1 – 18 years old), Malaysia

Severity	Year			Average (%)
	2006	2007	2008	
Fatal	485	469	578	511 (10.5)
Serious	1314	1223	1288	1275 (26.3)
Slight	2470	2330	2269	2356 (48.6)
Not Injured	707	628	785	707 (14.6)
Total	4976	4650	4920	4849

Source: Mohamed et al., 2011

Based on data provided by The Royal Malaysian Police, child casualties in motorcycle accidents averaged at 4849 persons annually, 10.5% were fatalities and the remainder received slight (26.3%) or serious injuries (48.6%) [9]. Moreover, Hamzah et al. [9] also suggested that as the victim's age increases, the casualty level increases as well. The practice of a children pillion without any sort of protection especially on foot-supporting devices other than holding tightly to the adult rider is commonly observed in residential and school areas [12]. In another study, Paiman et al. [13] have found that although at the maximum height of children aged nine years old, they still could not reach the motorcycle foot-board. There was a significant vertical difference between child pillion riders' feet relative to motorcycle foot-boards. Among the 233 participants, 22% were found to be not able to place their feet on the motorcycle foot-boards whilst sitting on the pillion seat. It was also found that the maximum height of students who were not able to reach the foot-boards was 1263 mm. The mean height of those who could not reach the foot-boards was 1137 mm, which was similar to the mean height of all the 7-years olds in this study (mean = 1160 mm). A Malaysian study examined the match between child anthropometry and pillion seat design and found children approximating seven years old could not reach the foot-boards [14]. In the United Kingdom, passengers must be able to sit astride and with feet on the foot-boards. While non-use of foot-boards may affect stability and safety during riding [15], the pillion stature and foot-board usage have not been studied as a risk factor. There is a crucial need to protect the children while they are travelling in motorcycles on roads in Malaysia. The creation and introduction of the correct type

of protection systems, regulations and standards will go a long way towards realising the vision for a safer travelling environment for the children in Malaysia [16]

However, currently there is no available product on the market that addresses the safety of children pillion while riding on the underbone motorcycles. The development of foot-board is significantly needed to prevent any further injuries towards children pillion. The foot-board is important as it provides a safety and stability to the children pillion during riding. Apart from being foot balancing, the foot-board act as a platform for the pillion to step on while riding. These parts will be located on both sides of a motorcycle. The main objective of this study is to design and develop an ergonomic, children user-friendly and universal foot-board for underbone motorcycles to reduce the risk of feet injury of the children pillion.

II. DESIGN METHODOLOGY

Design and development of PIJAK involving the identifying of market needs and design criteria as product benchmarking. The availability of safety systems was analysed and observed in the field of underbone motorcycles. This study mainly focuses on underbone motorcycles pillion foot-boards in a Malaysian context which commonly passenger riders are children. For time being, no research has been done regarding this matter. Most studies are focused on motorcycle helmets problem [9]. On the other hand, this research has been conducted using mixed method to reduce coverage and nonresponse problems, while at the same time to collect data from as many respondents as possible. A survey was conducted to identify the need and usability of the product, with the user interviews were sought to investigate more input from the initial data received to clarify and support the data. Moreover, to share a better experience and thought from the participants, observational study was conducted as well.

A. Survey

The team has conducted a survey of rider and pillion rider on identifying the problem regarding the children pillion ride, safety and market need on children pillion foot-board. To complete the survey, a total of 169 respondents; 84 males and 85 females which varied mostly by age (7 - >36 years old) from the state of Terengganu, Kelantan and Johor. The location of the respondents was selected based on justification where public primary schools were located in the countryside area. Fig. 1 summarizes the summary of respondents, their demographic background and the purpose of carrying children pillion.

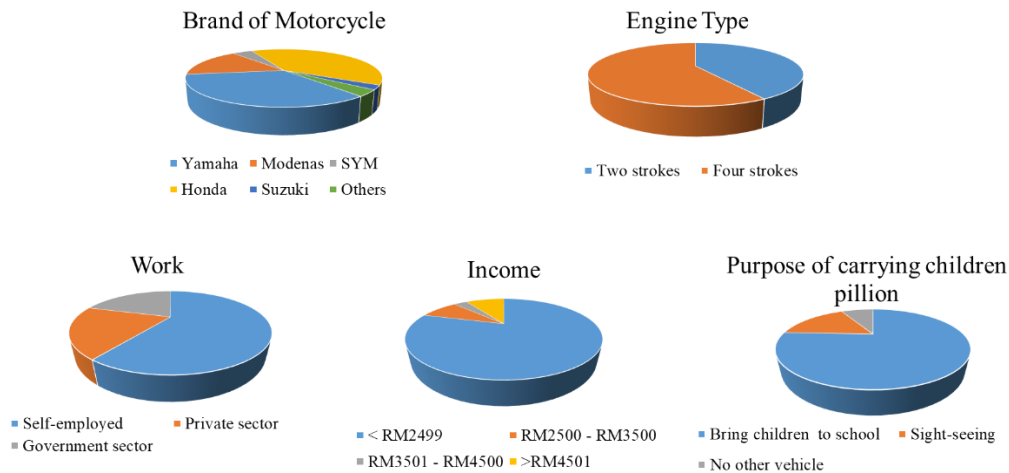


Fig. 1. Summary on motorcycle type, demographic background and purpose of carrying children pillion

Based on the survey, the most used of underbone class motorcycle was Honda, which consists of 40% from the market, followed by Yamaha, 34%. However, the locally made brand, Modenas was only scored 4% of the market. Moreover, the important part of this research was to understand as many types of brands of these motorcycles because the criteria of the outcome product should be universal attachable device. Overall, 60% of the motorcycle riders were self-employed and 79% of the respondents have a basic income that is less than RM2,499. The respondents were mostly parents who send or fetch their children from school using an underbone motorcycle as their main mode of transportation (76%). The main reason for this is due to the crowded area around the school which is difficult to be accessed by car.

However, another 17% of respondents claimed that they used to carry the children using motorcycle for sightseeing at the surrounding areas, whereas another 8% respondents said that they did not have any choices since they have no vehicles other than the motorcycle. A questionnaire was distributed to gather the information on children pillion and safety among the motorcycle riders. The reliability of the internal consistency of scale or test items in the questionnaire were validated and measured using Cronbach's Alpha test. An acceptable α value of 0.73942 was obtained from the test which confirmed the validity of the questionnaire. Table 2 summarized the level of concern by respondents on children pillion ride and safety.

Table- II: Level of concern by respondents on children pillion ride and safety

Children pillion ride and safety	Level of Concern*					Mean	SD
	1	2	3	4	5		
Children pillion face troubles when gets on and off the motorcycle	9 (5%)	43 (25%)	32 (19%)	63 (37%)	22 (13%)	3.27	1.13
The available design of foot-board is not suitable for children pillion	12 (7%)	46 (27%)	37 (22%)	63 (37%)	11 (7%)	3.09	1.09
The motorcycle can be easily controlled when children pillion gets on and off	13 (8%)	44 (26%)	25 (15%)	74 (44%)	13 (8%)	3.18	1.13
The motorcycle was in stable conditions during the ride	5 (3%)	25 (15%)	30 (18%)	83 (43%)	25 (12%)	3.58	1.01
Children pillion was in stable conditions during the ride	6 (4%)	39 (23%)	31 (18%)	72 (43%)	20 (12%)	3.36	1.07
The driver can easily carry the children pillion in unstable conditions	30 (18%)	68 (40%)	32 (19%)	33 (20%)	5 (3%)	2.49	1.09
Children pillion is not susceptible to risk and injuries when gets on and off the motorcycle	24 (14%)	58 (35%)	35 (21%)	38 (23%)	11 (7%)	2.72	1.16
Injury incident to the children pillion during the ride	24 (14%)	48 (28%)	40 (24%)	42 (25%)	15 (9%)	2.86	1.20
Children pillion 's foot has been hit by other vehicles during the ride	37 (20%)	48 (26%)	40 (22%)	42 (23%)	15 (8%)	2.73	1.25
Accident or near-miss accident happened while riding with children pillion	26 (16%)	42 (25%)	42 (25%)	41 (25%)	16 (10%)	2.87	1.22

*Rating: 1=strongly disagree, 2=disagree, 3=uncertain, 4=agree, 5=strongly agree
SD: Standard deviation

From the survey, 50% of the respondents agreed that children pillion face trouble using the available foot-board when getting on and off the motorcycle. When they were asked about the available foot-board design, 44% of the respondents agreed that the available design of foot-board is not suitable for children pillion whereas the other 22% of

respondents are unsure whether the foot-board is practical of well-functioned. On the other hand, 34% of the respondents are pleased with the available foot-board design. This may be due to the small figure and height of children that prevent them to use the foot-board efficiently.

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Respondents were asked about the balance when riding with children pillion. In general, balance is an important element for the driver to keep control over the motorcycle as it stands still, moves along the roadways at a variety speeds, and as it turns [17]. Most of the respondents agreed that the motorcycle is in stable condition when children get on and off the motorcycle (52%). During the ride, the rider can easily keep control of the motorcycle (55%) and the children pillion (55%). However, the riders agreed that they faced difficulty to control the motorcycle when the children pillion is in unstable conditions (58%). From a direct interview with the rider revealed that the existing of foot-board help the children when getting on and off the motorcycle easily. However, the foot-board is unusable for them while riding. Hence, this can be a very risky situation when it comes to children pillions.

When the respondents were asked about the risk of injury to the children pillion during the ride, 34% of the respondents agree that the children pillion are prone to be injured during riding. Incident and injuries have mostly happened when the children pillion gets on and off the motorcycle (49%). In addition to that, 31% of the respondents stated that the children pillion's foot had been hit by other vehicles during the ride and another 35% of the respondents have experienced a near-miss accident and lost control over the motorcycle when they carried children pillion. Safety of both driver and the pillion is the most important aspect to consider during riding. The impact of being hit or meet an accident will jeopardize the children mentally and physically in the future.

B. Interview

Interviews have been conducted to get more detail primary data as the researcher went on-site meeting with the motorcycle users themselves. To start the interview session with, sets of questions have been drafted out whereby two types has been used; structured and semi-structured questions. The structured interview has been used in a more formal session with an officer from the Road Transport Department (JPJ). However, semi-structured interviews have been conducted in a less formal area in a way to get reliable data from ordinary people. Respondents in this semi-structured interview are selected randomly. However, the criterion that they should have is underbone motorcyclist.

C. Observational Study

An observational study has been conducted in several areas in the state of Johor, Kelantan and Terengganu. School areas are the most crowded place as most of the pillions were primary school students (7 - 12 years old) and in some cases, kindergarten students (<7 years old). Fig. 2 shows the state of children pillion especially their leg and feet positioning when riding the motorcycle.

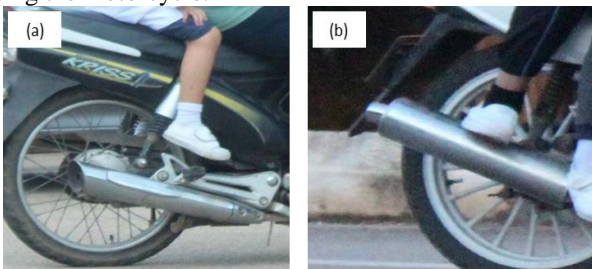


Fig. 2. (a) Children pillion's feet are left hanging and (b)

Children pillion's feet rested on the exhaust

Photo by: Ruwaidy Mat Rasol

Based on the team observation, the children pillion's feet are mostly left hanging since the available foot-board is not reachable due to their height as shown in Figure 2(a). In other cases, the children prefer to rest their feet on the parts of the engine or worst; on the exhaust of motorcycle as shown in Figure 2(b). This has become a habit since they felt more secure and stable while riding the motorcycle.

III. DESIGN CONCEPT AND DEVELOPMENT

A. Design Concept

The design of PIJAK was based on child's feet sizes as to suit the purpose as a foot-board for children pillion. Based on the ergonomic design factor, the 5th percentiles were considered; which represent the foot size of seven-year-old children. Besides, an oversize foot-board will risk the safety aspect of a motorcycle and does not meet the design requirement. There are several design criteria were included in the designing and development of PIJAK. The first one, PIJAK must be a universal pillion foot-board which mean that it can be attached or assembled to any brands of motorcycles. In this case, two samples of foot-board from Yamaha and Honda, the most popular brand of underbone motorcycle were taken as a reference. Also, PIJAK must be designed so that it is easy to be handled by the consumer (do-it-yourself concept). And lastly, PIJAK can be flipped up and down as to accommodate the adult pillion foot.

The design process involved three main stages including two-dimensional (2D) design, three-dimensional (3D) design and prototype developments. The 2D and 3D design were conducted using Solidworks Simulation, Version 2016. The completed 3D design of PIJAK prototype was analysed using Von Mises Stress (VMS) analysis and resultant displacement analysis to obtain the most suitable design for footboard

B. 3D Design Development

In the development of PIJAK foot-board, three prototypes were developed as shown in Fig. 3. All the developed prototypes are user-friendly and feature an adjustable foot-board design which is preferable in the design of a pillion foot-board. However, in Prototype 1, a high surface area was observed in the plate part which makes the foot-board heavier. The small hinges used in the prototype cannot withstand a higher load. All the drawbacks in Prototype 1 were further improved in Prototype 2 where the plate was designed with smaller surface area and bigger hinges. Prototype 2 was also designed with adjustable levelling system which can accommodate the different height of children pillion. However, the levelling system was not user-friendly and the foot-board was found to be unstable. Prototype 3 features a more appealing design with a wider part to hold the bracket so that the foot-board remain stable during the ride. However, this prototype offers only a single level system.

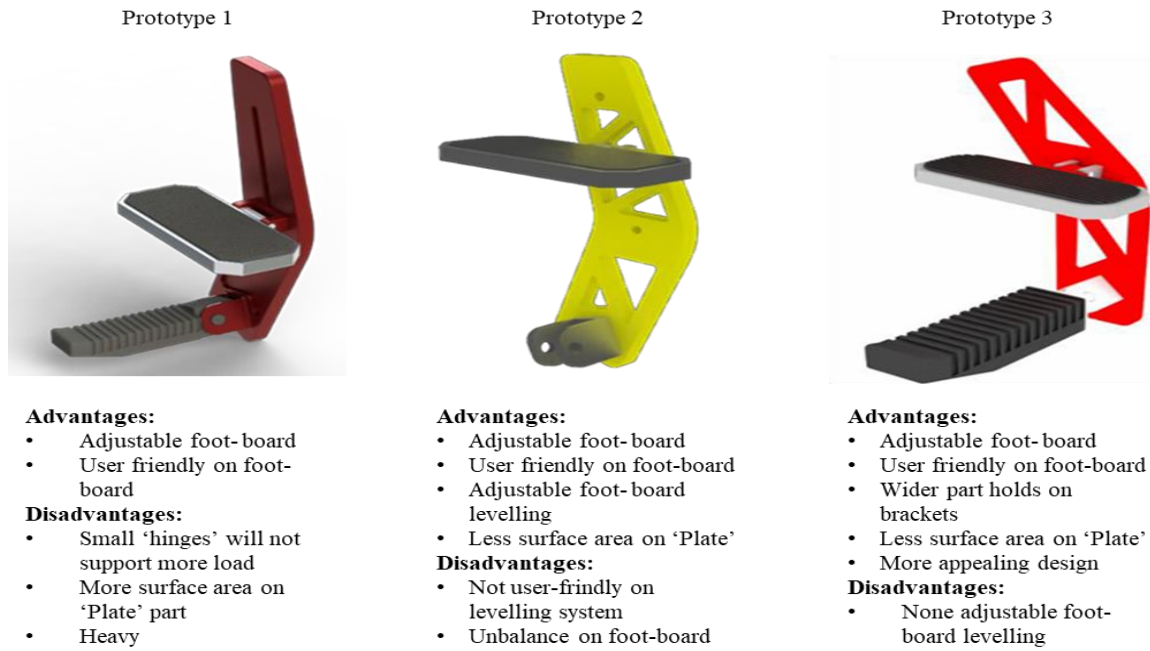


Fig. 3. 3D prototype design, advantages and disadvantages

IV. RESULT AND DISCUSSION

A. Design Analysis

Stress analysis has been conducted on the footboard and supporter parts where these parts hold the most vibration and load during pillion ride. Fig. 4 shows the VMS images of the three developed prototypes of PIJAK.

The VMS analysis is used to visualize the VMS field patterns, which represent a scalar field quantity obtained from the volume distortion energy density and used to measure the state of stress. During the analysis, the 3D models of the developed prototype were given a pressure of > 60 kg to represent the maximum load of a child.

From the stress analysis, it was found that Prototype 1 can only withstand a maximum pressure of $4.1301 \times 10^8 \text{ N/m}^2$. This might be due to the small design of the hinge which cannot tolerate a higher load. The design of the hinge was upgraded in Prototype 2, however, it can only handle a maximum stress level of $2.2280 \times 10^7 \text{ N/m}^2$. The foot-board prototype tends to bend with a higher load which jeopardize the strength and safety aspect of the foot-board. On the other hand, Prototype 3 shows a very significant result in term of stress management with a maximum stress value of $9.1757 \times 10^8 \text{ N/m}^2$. In Prototype 3, bigger hinge size was employed in the design of foot-board and the hinge was being supported to the plate part hence prevented the foot-board from bent down.

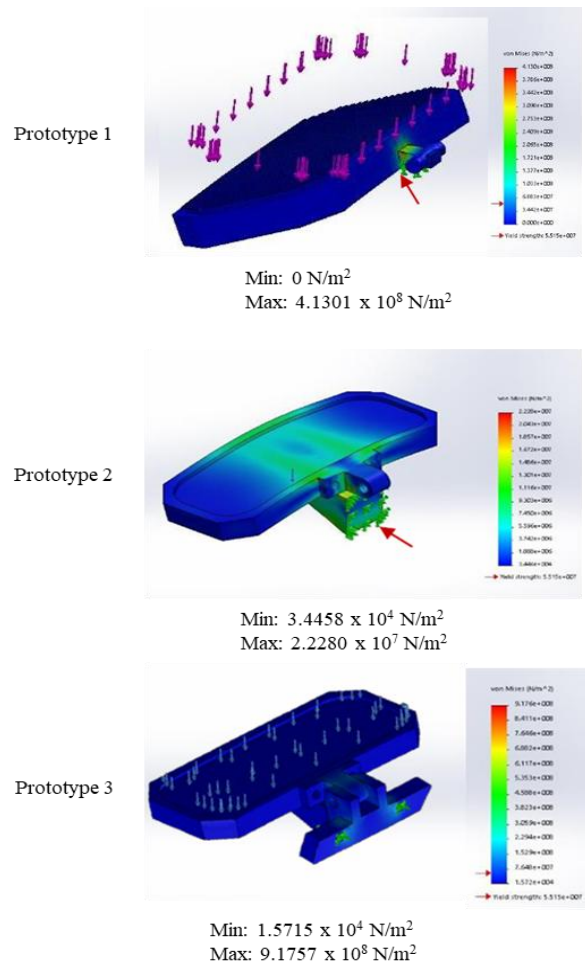


Fig. 4. Von Mises stress analysis

The resultant displacement analysis was conducted on the developed prototypes to identify whether they have a significant value on moving or displacement. The results of resultant displacement analysis

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were presented in Fig. 5. Based on the results, Prototype 1 has a resultant displacement value of 0.5652 mm, whereas 0.0473 mm resultant displacement was observed in Prototype 2. The highest resultant displacement was evaluated in Prototype 3 with 0.6410 mm. Although Prototype 3 has the largest resultant displacement, it does not affect the durability because of its moving parts. Furthermore, the gap of these parts has a significant tolerance to ensure the smoothness of its moving parts.

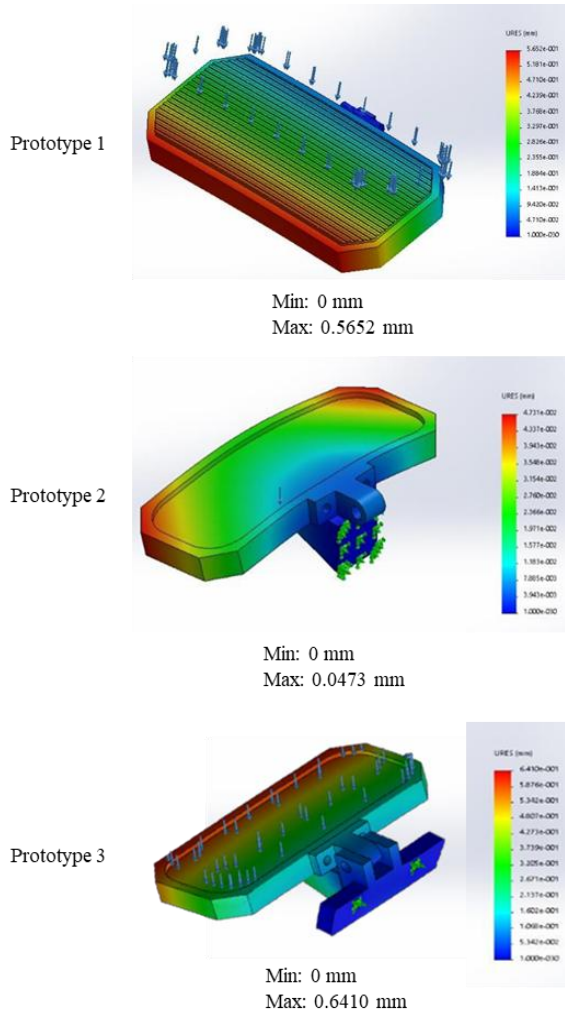


Fig. 5. Resultant displacement analysis

B. Final PIJAK Prototype

Based on the design analyses that have been conducted on all three prototypes, Prototype 3 was chosen as the most suitable design for PIJAK foot-board. Prototype 3 has overcome the disadvantages of the earlier developed prototype. Fig. 6 shows the exploded views of the final PIJAK prototype. PIJAK universal pillion foot-board consist of two main parts which are the foot-board and plate. It can be easily installed to the underbone motorcycle using the hinge and screw as illustrated in the Fig. 6.

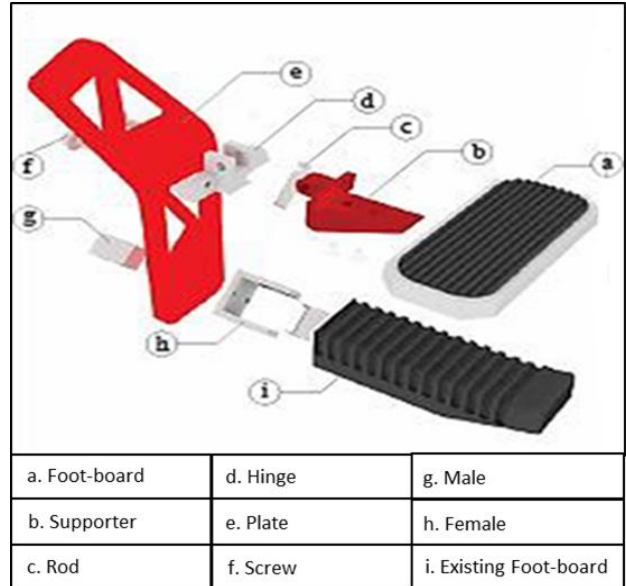


Fig. 6. PIJAK exploded view

C. Prototype Testing and Evaluation

The testing and evaluation of PIJAK prototype was evaluated using the usability test. The PIJAK foot-board was installed to an underbone motorcycle. Subjects were a volunteer staff from the faculty and his 7-year-old child. A list of short instructions as the testing procedures. Figure 7(a) shows the simple and easy installation of PIJAK foot-board on an underbone motorcycle. Figure 7(b) shows the adjustable feature of PIJAK foot-board where the footboard can be flipped down for children pillion use. In Figure 7(c), the PIJAK foot-board is being used by the child and lastly in Figure 7(d) shows that the PIJAK foot-board can be flipped up when not in use to accommodate adult pillion's foot on the available foot-board.



Fig. 7. (a) Installation of PIJAK foot-board (b) PIJAK foot-board being flipped down and ready to be used (c) PIJAK footboard is being used by the children pillion and (d) PIJAK foot-board being flipped up when not in use

Photo by: Ruwaidy Mat Rasul



After the usability test, both users (rider and children pillion) were asked to answer a simple survey. From the survey responses, both users agreed and satisfied with the performance of PIJAK foot-board. The rider had easily installed the PIJAK foot-board on the motorcycle. On the other hand, the children pillion had easily placed his foot on the PIJAK-board. Both rider and children pillion felt safe and assured during the ride with both of the children pillion's feet safely rested on the PIJAK foot-board. These findings show that the PIJAK foot-board has a good

V. CONCLUSION

There is a persistent need to educate parents and adults on the urgent undertaking of child safety whilst going in underbone motorcycle as a pillion passenger on Malaysian roads. Therefore, this paper highlights current safety design for children as pillion on underbone motorcycle and the steps undertaken to address the need to enhance children's safety and suggest possible remedial action and modification to counter the possible lack of awareness for children's safety whilst in these vehicles. A possible review of the Malaysian law pertaining to suitability of children riding pillion with a set age limit of should be carried out for the benefit of this vulnerable group. Engineering countermeasures should be implemented to create a safer and more crashworthy travel environment for the children pillion. For motorcycles, a device capable of providing some sort of protection to the child whilst riding pillion should be designed and developed. These findings are based on a strong understanding of the user population and its unique characteristics were necessary to develop a product to meet their needs, in terms of safety and comfortability. The researcher constantly designing, assessing, and modifying their designs throughout all the different stages of product development. These designs could be used by the designers and test participants, and modifications were able to be made quickly and easily with low-cost prototypes. Once components of the design were settled on, the team was able to make virtual models, assess the design for compatibility with the platform they were designed for, and conduct engineering analyses and human modelling analyses. By keeping the end-user and their influences in mind, designers working on other design problems were also being able to identify safety issues in other types of products and improve their designs to better meet the users' needs. The development and design of PIJAK foot-board are significantly improved to meet the requirement of the end-user. The important value of this product is it marketable as it can be useful and practical. With all the design process and analysis findings, Prototype 3 has been finalized and meets most of the consumer needs. Thus, benefiting from improved design, Prototype 3 design can be finalised and ready for manufacture.

ACKNOWLEDGMENT

The authors are thankful to the Universiti Sultan Zainal Abidin, for financial support under Dana Penyelidikan Universiti (DPU), UniSZA/2017/DPU/34.

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Ruwaidy Mat Rasul is specialize in Universal Design and Design Management. Currently he is active in product innovations and entered local and international competitions. Appointed as a Head of Center for Design Study, Faculty of Innovative Design and Technology, he is



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