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An Exploratory Study of Integrating Booster Seat Design on Rear Seat Vehicle in Static Test

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Abstract: Child Restraint System (CRS) is a safety seat created especially for child or small adult. The function of CRS is to protect or avoid child from any injury or death during vehicle crashes. This study presents a broad, comprehensive research effort that brings together industry and academic skill and uses numerous methodologies with countermeasures as the focus of applied research. The objectives of this study are to design mechanism for an integrated child seat booster for the rear seat and analyze the strength of the booster seat mechanism when loads applied on it. In order to get the seating reference point, 3D scanning process has been performed using car seat model from a toy car. A design of the booster seat mechanism is chosen for the reference based on the previous study. SolidWorks has been used in the designing and simulation of the static test process for the booster seat mechanism. The simulation has been performed to determine stress, strain and displacement of the integrated seat booster mechanism by applying different loads in static condition. The result from the simulation showed that when load D (37.08kg) was applied on the mechanism, it has the highest stress, strain and displacement which is 7689000N/m2, 2.22×10-5 and 1.74×10-2mm respectively. This is due to the fact that the more the force applied on the mechanism, the greater the stress, strain and displacement reacted on the booster seat mechanism. The success of this project will able the researcher and consumer to improve the safety of the child occupant in the CRS during the event of crash.

Keywords: CRS, booster seat, static test, stress, strain, displacement

1. Introduction

In early 1960's, child restraint system (CRS) for cars has been develop [1]. Child restraint system or can be called as booster seat is a seat designed especially for children or small adult. The advantages of using CRS are it can help to protect or avoid the user from any injury or death during motor crashes [2-6]. During past 40 years, various child restraint system has been developed to enhance the protection for children or small adults. Isaksson- Hellman (2015) and Jakobsson (2015) showed a clear upward trend of steadily increased safety for children in cars during this time period in Sweden [7-11].

In 2018, the World Health Organization (WHO) Global Status Report on Road Safety indicated that among children and young people aged 5 to 29 years old, road injuries were the leading cause of mortality. Nearly 30 percent of all road traffic fatalities occur while people are in their vehicles. First and second on the list of fatalities among children aged 1 to 4 and 5 to 9 years old in Malaysia are those carried in private automobiles (43.8 percent and 30.2 percent, respectively) [2]. In China, according to data from China's Ministry of Public Security's Traffic Management Bureau, there were 27,735 traffic-related deaths of children under the age of 15 between 2005 and 2010 [3]. Despite major advancements in child safety system, vehicle collisions remain the top cause of child fatality [12-14].

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Child Restraint System (CRS) are developed to accommodate the morphological distinctions between adults and children to provide effective injury protection in the rear seat. The skeleton and skull size of children and adults are vastly different [4]. Serious injuries can be avoided if new born and toddlers transported in the opposite direction. Child safety seats were shown to reduce the risk of fatality among kids ages two to six by 28 percent. Currently, majority of existing restraint designed in the vehicles are provided for adults instead of small child. Belt-positioning booster cushions were introduced in the late 1970's. Booster cushions, booster seats (with backs), and integrated (built-in) booster cushions are the most common belt-positioning boosters nowadays. Booster seats and kid restraints are attached to an adult seat belt. The integrated boosters were designed to make it easier to use and to reduce the risk of misusing the product. For Volvo automobiles from 1991 onwards, they may be found positioned either in the middle or outboard of the rear seats, with three-point seat belts [15-18].

A booster seat help elevates a child up to a more proper shoulder belt position so that the belt moved across the focal point of the chest and between the shoulder and neck. This repositioning of the belt can give comfort to the occupant instead of having the belt in an unsafe position. This placement of belt can help prevent the injury during crashes. Research indicated that children in booster seats were 60% less likely to be injured in a car collision than those in seatbelts alone. The booster enables the geometry of the adult seat belt to operate more effectively in relation to the kid passenger while using the booster. The booster lifts the kid to a height where the lap portion of the adult seat belt may be placed over the thighs, reducing the likelihood of the abdomen interfering with the belt [19-21]

There are many cases that causes death to the children during motor crashes. This is because their parent did not aware about the using of Child Restraint System (CRS). Therefore, Malaysia government decided to enforce the child restraint legislation becomes mandatory started 1 January 2020 to avoid any death among children during motor crashes. Integrated booster seat is an alternative way to overcome parent complaint about space to keep the child car seat while not used. The main objective for this study is to design mechanism for the integrated booster seat and analyze the strength of the booster seat mechanism in static test. This study will be conducted using simulation method and SolidWorks has been chosen as the platform for the simulation. From the simulation, the stress, strain and displacement of the booster seat mechanism when several loads were applied on it will be determined.

2. Methodology

The approach utilized to design the mechanism and analyze the strength of the integrated booster seat is described in this chapter. The proposed study will go further into the tools and techniques, as well as the benefits and drawbacks of achieving practical feasibility.

2.1 3D Scanning

This activity was very important to get the reference surface before designing the integrated booster seat. Since we do not have the reference drawing and actual 3D data, we applied the reverse engineering method by scanning the actual seat prototype. Before the activity started, we prepared the seat model for the 3D scanning. For the seat model, we derived it from a toy car. During the process, there was an error occurred which is the 3D scanner could not scan several reference points that was patched at the seat model. This error has led to an uncompleted image of the seat model Figure 1 shows the image that we got after the scanning process. However, the image still can be used as the reference drawing for the car seat.

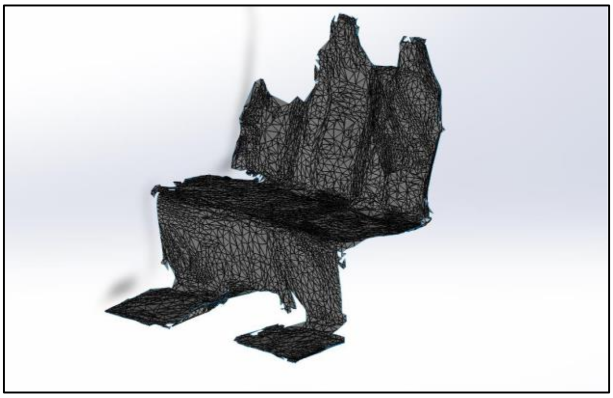

Fig. 1 - Image from the 3D scanning process

2.2 Designing Mechanism of Integrated Booster Seat

Mechanism design is an economic theory that aims to understand the processes that may be used to accomplish a certain end or result in a given situation. This progress was important to determine the mechanism that will used for the integrated booster seat and how it works. We used the design from a previous study as a starting point for the process of developing the mechanism for the booster seat. SolidWorks has been used during the process to design the mechanism. The rod, the anchorage, and the seat plate comprise the mechanism structure of the booster seat. All of the parts have been modelled one by one in the part drawing and were assembled in the assembly drawing. Figure 2 shows the drawing in SolidWorks of the mechanism for the booster seat.

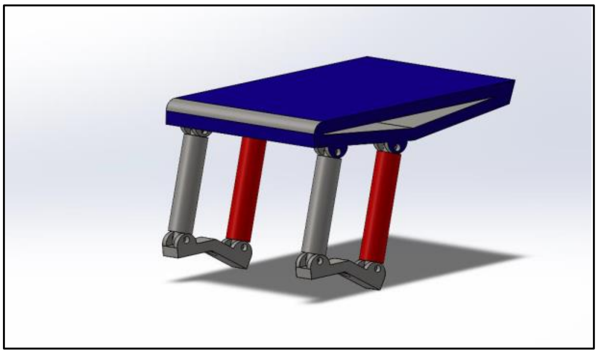

Fig. 2 - Drawing in SolidWorks of the mechanism for the booster seat

2.3 Modelling Integrated Booster Seat

Volvo developed the original concept for this booster seat, which was then used as a model for this research. In addition to these modifications, there have been a number of other changes, including the size and design of the booster seat. The integrated booster seat was designed using the Proton Saga's rear seat dimensions as a reference. The reference drawing for a car seat collected during the 3D scanning process proved extremely useful when modelling the integrated booster seat. SolidWorks was used for the modelling and construction. First a rough sketch was made, then was refined in SolidWorks. Figure 3 is a SolidWorks drawing of an integrated booster seat.

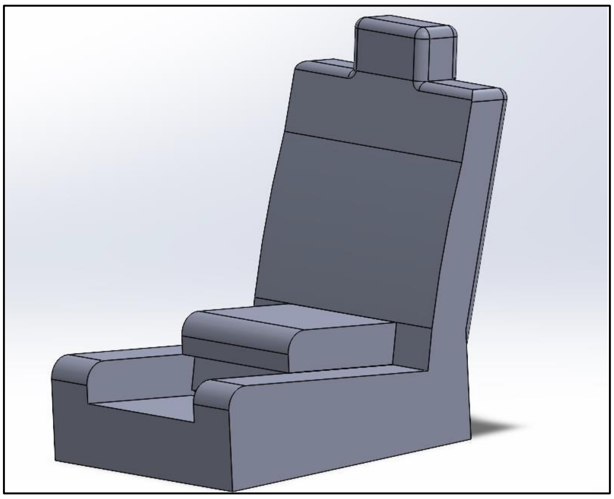

Fig. 3 - Drawing for the design of integrated booster seat

2.4 Simulation Setup

SolidWorks, a CAD software, was used to simulate the static test. Initially, the assembly drawing showed the mechanism attached to the integrated booster seat. The next step was to decide on the materials for the mechanism and integrated booster seat. For the mechanism, AISI 1020 stainless steel has been chosen because of its strength and durability while the polyurethane foam was chosen as the integrated booster seat’s material. The fixed geometry of the seat, including the bottom and back surface, has been determined. Then, forces were applied to the booster seat's upper surface. Figure 4 depicts the simulation setup. The purple arrow indicates force direction, while the green arrow indicates fixed geometry.

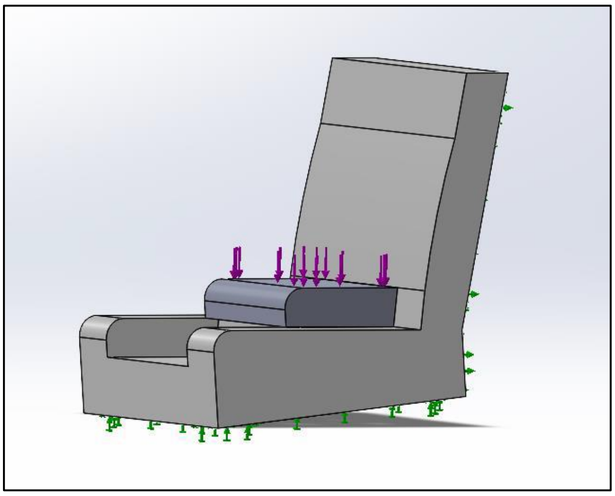

Fig. 4 - Simulation setup

2.5 Static Test

In order to determine the strength of the integrated booster seat's mechanism, a static test simulation was carried out. The data on stress, strain and deformation for the booster seat mechanism when loads applied on it was gathered via this computer simulation. It was decided to run the simulation with four different weights, each weighing 18kg, 27kg, 36kg, and 36kg plus 3 percent for safety factor, for a total of four different loads. The loads have been chosen in line with the findings of the previous research.

3. Results and Discussion

The data acquired as a result of the experiment will be discussed in this chapter. This research focuses on the data and that were collected throughout the simulation utilizing the SolidWorks software. The data then is retrieved to Microsoft Excel, which was used to create graphs comparing the stress, strain and deformation of the booster seat mechanism when four different loads applied on it. The simulation was conducted to determine the strength of the integrated booster seat mechanism.

3.1 Static Test Analysis

The data has been collected from the simulation and the stress, strain and displacement of the booster seat mechanism will be discussed in this section. Figure 5 show the effect from the simulation on the booster seat mechanism when loads were applied on it. From the figure, we can see the shape of the top plate has changed during the simulation. This is due to the loads that were applied on it.

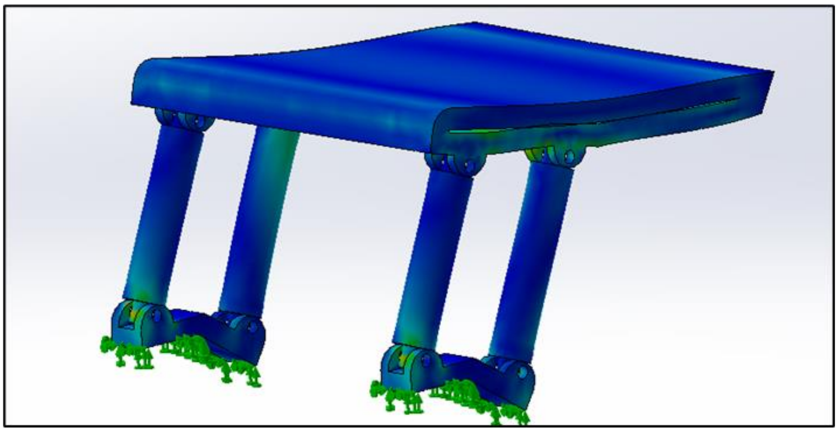

Fig. 5 - Effect from simulation

3.1.1 Stress Analysis

Stress is described as the force per unit area generated by external forces, unequal heating, or persistent deformation. Stress may be used to accurately describe and predict the elastic, plastic, and fluid behaviour of materials. Based on

Figure 6, it shows the chart for the stress analysis result that collected from the simulation. Based on the chart, we can conclude that the bigger the amount of loads placed on the booster seat mechanism, the greater the stress occurred on the mechanism. The mechanism experienced the greatest amount of stress, 7689000 N/m2, when the load D, which was 37.08kg, was applied to it. When the mechanism is subjected to load A, which is 18kg, the stress that occurs on the mechanism is 3732000 N/m2, which is the lowest reading out of all the data. When load B (27kg) and C (36kg) applied on the mechanism, the amount of stress that occurred was 5599000 N/m2 and 7465000 N/m2 respectively.

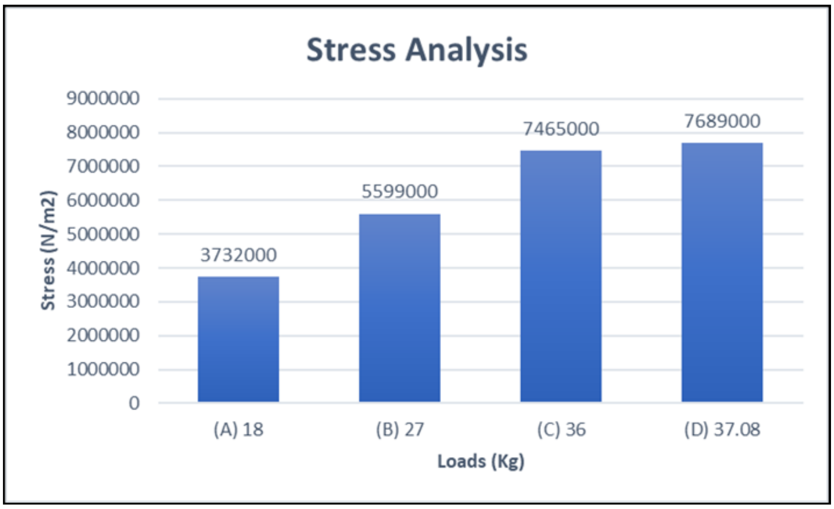

Fig. 6 - Charts of stress analysis

3.1.2 Strain Analysis

Strain is the amount of deformation experienced by the body in the direction of force applied, divided by the initial dimensions of the body. Figure 7 shows the chart of the strain analysis result that we gained from the simulation. Based on the charts, we can conclude that the bigger the amount of load applied on the mechanism, the greater the strain occurred on the mechanism. When applied to the mechanism, Load A (18kg), produces the lowest number of strains, which is 1.08×10-5. When the load D (37.08kg) was applied to the booster seat mechanism, the highest amount of strain was observed, which was 2.22×10-5. When the mechanism was subjected to loads B (27kg) and C (36kg), the amount of strain experienced was 1.62×10-5 and 1.62×10-5, respectively.

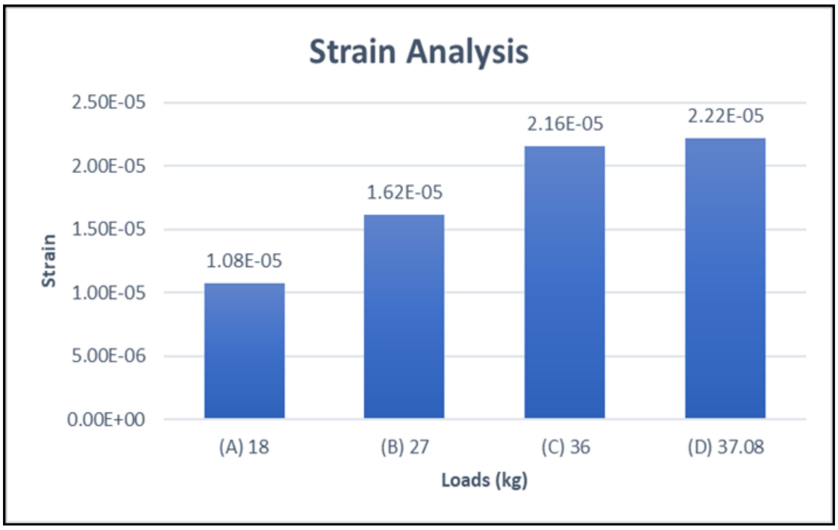

Fig. 7 - Charts of strain analysis

3.1.3 Displacement Analysis

Other than stress and strain, displacement also occurred when a load applied on the booster seat mechanism. Displacement is the action of moving something from its place or position. In this case, displacement that we measured is the movement of the booster seat mechanism when loads were applied on it. Figure 8 illustrates the displacement analysis result that we gained from the static test simulation. Based on the charts, we can conclude that the bigger the amount of load applied on the mechanism, the greater the displacement occurred on the mechanism. The mechanism experienced the highest displacement among the others which is 1.74×10-2mm when load D (37.08kg) applied on it. The lowest displacement, 8.43×10-3mm occurred when load A (18kg) was applied on the mechanism. It was found that the amount of strain experienced by the mechanism when subjected to loads B (27kg) and C (36kg) was 1.27×10-2mm and 1.69×10-2mm, respectively.

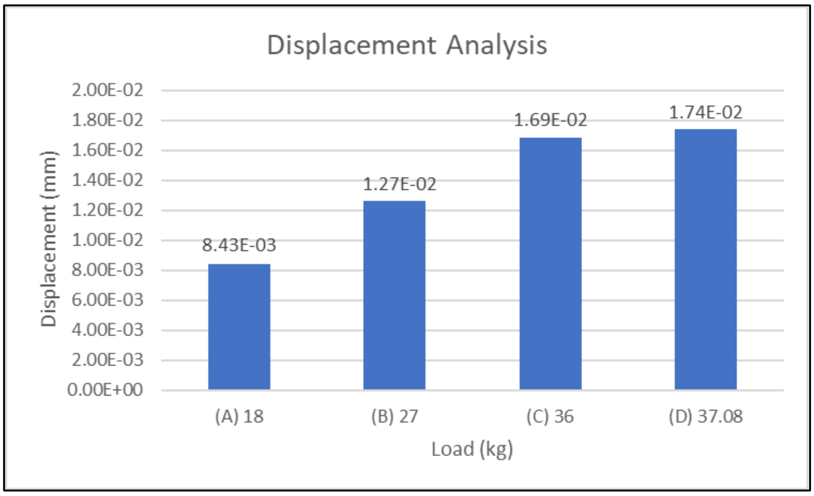

Fig. 8 - Charts of displacement analysis

3.2 Discussion

Table 1 - Results of stress, strain and displacement

Loads (kg)	Stress (N/m2)	Strain	Displacement (mm)
A (18)	3732000	1.08 × 10-5	8.43 × 10-3
B (27)	5599000	1.62 × 10-5	1.27 × 10-2
C (36)	7465000	2.16 × 10-5	1.69 × 10-2
D (37.08)	7689000	2.22 × 10-5	1.74 × 10-2

Table 1 illustrates the overall result for stress, strain and displacement for the four different loads. From the analysis, it was clearly showed that load D which is 37.08kg has the highest stress, strain and displacement when the force applied on the booster seat mechanism compared to the other loads which is 18kg, 27kg and 36kg. This is because the bigger the force applied on the mechanism, the greater the amount of stress, strain and displacement that the mechanism experienced. The relationship between stress and strain is that they are exactly proportional to each other up to a point when they reach an elastic limit.

A solid experiences strain in proportion to applied stress according to Hooke's law, and this should occur within an elastic limit of that solid. In this study, we can conclude that the booster seat mechanism was able to hold the loads that was subjected to it without collapse. The simulation results also indicate that the integrated seat booster is safe to use in term of product constraints. However, some aspects should be taken into account in future researchers where the safety parameters of the child during impact and performance of the seat booster in dynamic condition.

We can make an assumption to relate about how the stress that experienced by the mechanism can affect the injury risk of the occupant. For example, if the mechanism is subjected to high stress when loads are applied to it, the risk of injury to the occupant may increase as a result of the high levels of vibration. Fatigue damage to the mechanism may result from prolonged exposure to high stress. To calculate the injury and determine the relationship between injury and stress, further study with the use of Anthropomorphic Test Device (ATD) is very recommended.

4. Conclusion

As a result, the main objective of the research is to determine the stress, strain, and displacement of the integrated booster seat mechanism when static loads are given to the seat mechanism in a static condition. It was decided to run the simulation with four distinct loads, which were load A (18kg), load B (27kg), load C (36kg), and load D (37.08kg). The simulation has been performed using a CAD software which is SolidWorks. The data that had been gathered from the simulation was converted into Microsoft Excel in order to produce graph for each analysis. Thus, the objective of an exploratory study of integrating booster seat design on rear seat vehicle during static was achieved. The result from this study enables a further study of the integrated booster seat. Therefore, the researchers are able to conduct detailed development process on the integrated booster seat.

The position of the seatbelt is very important in order to minimize the severity of injury among occupant in the booster seat during impact. By putting the seatbelt in higher position, it will reduce the occupant's chest deflection. However, the higher position of the seat belt can cause an injury to the occupant's neck and it is more dangerous than the chest deflection. Therefore, a further study can be conducted to determine the best height of the booster seat so that the seat belt is located at the right position and will help to reduce the injury during impact.

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