Study on Movement & Occupant Injury Based On The New FAR SIDE Test

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Abstract. The occupant movement and injury of the new Euro NCAP FAR SIDE test are taken as the research object, with the theoretical analysis, sled test and CAE model. The mathematical model of the far side dummy movement is established, and the main factors affecting the dummy's displacement are analysed. The injury characteristics of the far side dummy under the sled test are obtained, and the main causes are studied. And finally, the optimization scheme of the FAR SIDE test is proposed.

1. Introduction
At present, the occupant protection on the impact side is mainly considered in the aspect of the safety performance design of automobile. However, the occupant injuries on the non-impact side (the far side) are ignored. The statistics of European traffic accidents show that nearly half of the injuries cases above MAIS 2+ level (concise injuries level-moderate injuries) involve non-impact side occupants\cite{1}. Therefore, the Euro NCAP new car assessment procedure introduced a new type of FAR SIDE test to evaluate the non-impact side occupant injuries, and it has been officially implemented in 2020. The test procedure includes two sled tests, respectively based on the AE-MDB side impact test waveform and the side pole impact test waveform. A WorldSID 50th dummy is placed on the non-impact side, and the head displacement value and the occupant injury criteria are used as the evaluation basis\cite{1}. It puts forward new requirements for the side impact performance of the vehicle. Therefore, the occupant injuries and improvement plan under the new FAR SIDE test are studied in this paper.

Figure 1. Euro NCAP FAR SIDE test\cite{1}
2. FAR SIDE dummy movement analysis
As shown in Figure 2, the occupant position on the impact side is called the near side, and the non-impact side occupant position is called the far side\(^2\) in a side impact test.

![Figure 2. The position of the near side and far side occupants](image)

Studies have shown that the impact load of the vehicle body is closely related to the injuries of the occupants at the far side position\(^3\). When a vehicle in the crash, the passenger compartment of the impacted vehicle is subjected to lateral acceleration and impact loads. Due to the lateral inertia, the far side dummy comes out of the seat belt, and the chest and abdomen collide with the seat back flanks and the center armrest. After the chest and abdomen are blocked, the upper torso of the dummy will continue to rotate around the point which contact with the center armrest. At the same time, the head will be displaced relative to the torso. After the head speed is equal to the vehicle speed, rebound phenomenon occurs, as shown in Figure 3.

![Figure 3. Schematic diagram of the movement of the far side dummy in a side impact](image)

In the figure, “H1” is the vertical distance from the center of gravity of the dummy's head to the cushion. “H2” is the vertical distance from the center armrest to the cushion. Point “P” is the contact point between the dummy and the center armrest. “H” is the vertical distance from point P to the center of mass of the dummy's head. “A” is the horizontal distance from point P to the center of mass of the dummy's head. “S” is the distance from point “P” to the center of mass of the dummy's head. “α” is the angle between line “S” and the horizontal when the dummy is in contact with the center armrest. “β” is the angle between line “S” and the horizontal at the maximum displacement of the dummy. “m1” is the mass of the dummy above the contact point. “h” is the center of gravity of the dummy mass above the contact point. “a” is the acceleration impact load. “k” is the torsional stiffness of the dummy above the contact point. When the head displacement of the dummy is at its maximum, the horizontal and vertical displacements of the dummy head are:

\[
H = H_1 - H_2
\]

\[
S = \sqrt{H^2 + A^2} = \sqrt{(H_1 - H_2)^2 + A^2}
\]

\[
S_{\text{horizon}} = S \cdot \cos \beta - S \cdot \cos \alpha = \sqrt{(H_1 - H_2)^2 + A^2}(\cos \beta - \cos \alpha)
\]

\[
S_{\text{vertical}} = S \cdot \sin \beta - S \cdot \sin \alpha = \sqrt{(H_1 - H_2)^2 + A^2}(\sin \beta - \sin \alpha)
\]

\[m \cdot a \cdot h = k(\beta - \alpha)\]
When the dummy is determined, "H1", "A", "α" are fixed values, and from the formula, it can be concluded that the maximum displacement of the dummy is related to "H2" and "β". When the height of the center armrest increases, the maximum displacement of the dummy head shows a decreasing trend. "β" is positively correlated with the impact acceleration load “a”. The greater the impact load, the greater the rotation angle of the dummy's upper part, which results in greater head displacement.

When the type and size of the dummy at the far side position change, it can be concluded from Equations (3) and (4) that the larger the size of the dummy, the greater the displacement of the head during a side impact with greater risk of injury. From Fig. 4 and Fig. 5, it can be concluded that the sitting height of the 50th dummy is 909±9mm and the sitting height of the 5th dummy is 780±8mm. It indicates that the 50th dummy at the far side position has a higher head displacement and injury risk than the 5th dummy.

In summary, for a certain vehicle, the head displacement of the dummy at the far side in a side impact is related to the height of the center armrest, acceleration shock load and dummy size. These should be considered comprehensively when analysing the far end displacement.

3. Euro NCAP FAR SIDE test study
In order to further explore the occupant injuries and displacement of the new FAR SIDE test, the sled test analysis was carried out according to the Euro NCAP test regulations.

3.1. FAR SIDE test setup
The WorldSID 50th dummy is placed at the driver position, and the sled impact waveform is loaded on the passenger side, so that the driver position is the far side position. The direction of the WorldSID 50th dummy sensor is adjusted to the right side. The longitudinal centerline of the vehicle is 75 degrees to the acceleration direction of the sled, and the 60km/h AE-MDB side impact acceleration waveform is amplified by 1.035 times for FAR SIDE test. Figure 6 shows the shock waveform of the sled test with the body-in-white.
The passenger compartment is set up according to Table 1, and the WorldSID 50th dummy is positioned.

| Adjustment          | WorldSID 50th dummy passenger compartment position adjustment |
|---------------------|---------------------------------------------------------------|
| Seat fore/aft       | 20mm backwards in the middle position                         |
| Seat base tilt      | Middle position                                               |
| Seat height         | Lowest position                                               |
| Torso angle         | Otherwise 23° to Vertical                                      |
| Headrest height     | Middle position                                               |
| Headrest tilt       | Manufacturer's design position or middle position             |
| Seat lumbar support | Manufacturer's design position or fully retracted             |
| Arm-rests           | Lowered / in use position                                     |
| Steering wheel vertical position | middle position                   |
| Steering wheel horizontal position | middle position            |
| Seat belt anchorage | Initially, manufacturer’s 50th percentile design position     |

The 46-channel data of the far side WorldSID 50th dummy is collected to evaluate the injuries of the dummy.

At the same time, a reference plate is welded vertically at the rear of the white body, and a checkerboard with a unit of 50mm×50mm is pasted on the plate. Color marks are drawn on the passenger seat, interior trim and checkerboard reference board to assist in judging the movement posture of the dummy. The meanings of the marking lines of each color are as follows: the red line is the maximum intrusion point of the door inner panel of the actual vehicle impact AE-MDB test (speed 60km/h); the orange line is the center line of the passenger seat; the yellow line is the passenger seat 125mm inward from the center line, the green line is 250mm inward from the center line of the passenger seat, and the blue line is the center line of the central armrest, as shown in Figure 7. The body mark and reference coordinate checkerboard are shown in Figures 8 and 9.
Install 4 vehicle-mounted cameras on the crossbar welded at the front of the white body through the designed bracket, keep each vehicle-mounted camera parallel. F2.4/3.5mm lenses are used to calibrate the orientation of the vehicle-mounted camera before the test, such as Shown in Figure 10.

3.2. Movement of the dummy

After the test conditions are set, the sled test waveform is loaded. The WorldSID 50th dummy at the far side position moves to the near side under the action of inertial force, and gradually moves out of the seat belt. The side of the abdomen collides with the central armrest, and the head and neck quickly swing to the passenger side. When the chest is in contact with the central armrest, the abdomen is blocked and stops moving. Meanwhile, the head, neck, and upper chest continue to move under the action of inertial force, causing serious neck bending. Subsequently, the WorldSID 50th dummy swings to the non-impact side. As the dummy comes out of the seat belt, the motion of the dummy is unconstrained, which increases the risk of injuries from impact between the dummy and the interior of the passenger compartment. The movement process of the far side dummy is shown in Figure 11.
Figure 11. The movement of the FAR SIDE dummy

Through the analysis of the on-board high-speed camera image, the maximum displacement of the WorldSID 50th dummy in the Y direction is 809.6mm, which exceeds the orange marking line. Through this sled test, it can be seen that if there is no protective measures such as far side airbags, the far side occupants will slip from the seat belt during the impact and move to the near side greatly. During the rebound process, the movement is very random due to the slip from the seat belt, which leads to an increased risk of injury. In a side impact, the occupants in the car are likely to collide with the interior trim and cause injuries under the lateral impact load[4]. It can be seen from Fig. 12 that after the WorldSID 50th dummy rebounds to the far side, the head collides with the A-pillar of the body-in-white and causes hard contact injury. Therefore, the risk of far side occupant injury not only exists during the impact phase, but also in the rebound process. It should also be paid attention. Because the dummy comes out of the seat belt during the rebound process, the motion trajectory is difficult to control, and the impact with the vehicle interior is more random.

Figure 12. The head of the dummy collides with the BIW A-pillar

3.3. Dummy injury analysis

The injury criteria of the far side dummy is obtained from the Euro NCAP test evaluation program, as shown in Table 2. The main parts of the dummy, such as the head, chest, abdomen, and lumbar spine, are shown in Figs13-18.
According to the dummy injury curve and injury criteria data, it can be concluded that the more serious injuries of the WorldSID 50th dummy is concentrated at the moment of the neck and lumbar spine. These injuries are mainly caused by the bending and relative displacement of the dummy’s neck and lumbar spine during the impact. Therefore, it can be concluded that in the far side impact test, the key is to restrict the movement of the dummy and avoid the relative displacement between various parts caused by the tilt movement of the dummy. In addition, it is also necessary to pay attention to the injuries caused by the dummy’s rebound. From the injury curve, it can be concluded that when the time of the dummy is about 366ms, the head and neck injury curves have large peaks. This is caused by the impact of the head and the A-pillar during the rebound movement of the dummy (Figure 12). The head HIC15 caused by hard contact reaches 395, which is greater than the HIC15 value of 114 caused by the near side movement of the dummy in the sled test. Therefore, it is very important to effectively limit the movement of the dummy in the far side test. The protective measures to the far side dummy in the vehicle safety design are very necessary.

In summary, when the occupant is at the far side position, the occupant will get out of the seat belt due to the side inertial force, and the lower end of the chest and abdomen will collide with the seat side wing or the interior of the central armrest, causing injuries. Due to the relative movement of the torso parts, the neck and lumbar spine bear a large bending moment in a impact, causing serious injury. In the rebound phase, the dummy's posture is out of control due to the release of the restraint of the seat belt. There is a greater risk of impacting with interior.
4. Far side occupant protection measures
Based on the above FAR SIDE test, it can be concluded that when the dummy moves to the near side, it is difficult for the safety belt to restrict the side displacement of the dummy, which results in the dummy's movement cannot be effectively restrained. Due to the relative displacement between the various parts of the trunk, the neck and lumbar spine bear a large bending moment load. During the rebound phase, the dummy is unconstrained, and it collides with the interior of the passenger compartment and A-pillar, causing serious injuries. Therefore, in far side occupant protection, limiting the initial displacement of the dummy is particularly important, and effective measures should be taken to limit the dummy to the initial position. The analysis in the first section shows that the displacement of the far side dummy is related to the center armrest, dummy size and test impact load. For the specific Euro NCAP FAR SIDE test, the size of the dummy and the test impact load are certain, and the improvement space of the center armrest is limited. As the main technical means of impact safety, the airbag can effectively buffer the impact energy and limit the movement of the dummy. Therefore, in the simulation model, an airbag model is established on the inner side of the far side occupant, and the movement of the dummy with or without the far side airbag is compared. As shown in Figures 19-21, the airbag can effectively reduce the initial displacement and the final displacement avoiding the large displacement of the head. At the same time, when the airbag acts between the dummies on both sides, it can buffer the impact energy, avoid hard contact between the dummies on both sides, and further reduce impact injuries[5].

Figure 19. Movement of the dummy without far side airbag

Figure 20. Movement of the dummy with a far side airbag

Figure 21. Displacement of the dummy with or without the far side airbag
5. Summary
In this paper, the Euro NCAP new FAR SIDE test is studied through theoretical analysis, sled test and CAE simulation, and the following conclusions are drawn:

(1) The maximum displacement of the far side dummy is related to the height of the center armrest, acceleration load and the size of the dummy. When the height of the center armrest increases, the maximum displacement of the dummy head shows a decreasing trend. The greater the acceleration shock load, the greater the rotation angle of the dummy's upper part. And the larger the size of the dummy, the greater the displacement of the head.

(2) For the FAR SIDE test without a far side airbag, the WorldSID 50th dummy's greater injuries is concentrated on the moment at the neck and lumbar spine. These injuries are mainly caused by the bending and relative displacement of the dummy's neck and lumbar spine during the impact. The far side dummy is easy to come out of the seat belt and cannot be effectively restrained. During the rebound phase, there is a risk of secondary impacts with vehicle interiors and A-pillar.

(3) Limiting the initial displacement of the far side dummy is the key to reducing the risk of injury. The far side airbag can effectively buffer the impact energy of the far side dummy, reduce the initial and final displacement, and is an effective means to protect the far side occupants.

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