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Study on the Truck Target of AEB Test

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Abstract:

Background**:** Rear-end accidents between passenger car and truck can cause great harm to passengers, and Automatic Emergency Braking System/AEB test can reduce it. However, domestic and foreign standards and regulations have not yet covered AEB test between passenger car and truck.

Objective**:** To support the standardized performance evaluation of AEB, this paper presents a method of design for truck target that can be used for AEB test.

Method and Material**:** Based on 166 rear-end accidents between passenger car and truck in the Future mobile traffic Accident Scenario Study/ FASS, the appearance and reflection characteristics of truck end are extracted by data mining, the color of truck end is extracted by K-means clustering algorithm, and the feasibility and effectiveness of the truck target is verified by real vehicle tests, in which the truck target is stationary, the velocity of the test vehicle is 50km/h, and the overlap is 100%.

Conclusions**:** A method for extracting and designing AEB truck target based on accident data is provided in this article,and this can be used in vehicle active safety test.

Keywords: AEB test; Rear-end accidents between passenger car and truck; Truck target

1 AEB car-to-car test

The popularization of Automatic Emergency Braking System/AEB installation can greatly avoid the occurrence of rear-end collision accidents, and many vehicle manufacturers have payed more and more attention to this technology[1][2]. Therefore, based on the demand for AEB development and test, domestic and foreign mainstream test institutions have developed AEB test and evaluation procedures.

From 2014, Euro-NCAP officially introduced AEB car-to-car system test protocol, including three test scenarios: Car-to-Car Rear Stationary/CCRs, Car-to-Car Rear Moving/CCRm and Car-to-Car Rear Braking/CCRb. In recent years, the scenarios have been continuously enriched, adding Car-to-Car Front Turn-Across-Path/CCFtap, Car-to-Car Crossing Straight Crossing Path/CCCscp, Car-to-Car Front Head-On Straight/CCFhos and Car-to-Car Front Head-On Lane change/CCFhol. In these test scenarios, the AEB test and evaluation protocol by Euro-NCAP is mainly aimed on M1 passenger car. The test object is covered with PVC material, which can replicates the visual, radar and LIDAR attributes of a typical M1 passenger car. The initial AEB test target vehicle of Euro NCAP is a balloon vehicle developed by Continental.

AEB test was incorporated into the evaluation range in 2013 first time by IIHS. The test procedure is based on a potential rear-end collision in which the struck vehicle is not moving prior to impact. The stationary vehicle in the test is replaced with an impact-able target representing a passenger car. According to the test results, 85% of the vehicles can pass the original test speed standard, which is planned to be raised from 20km/h and 40km/h to 56km/h and 72km/h in 2023[3][4].

In China, C-IASI 2017 version and CNCAP 2018 version introduced AEB test project. At present, the test scenarios cover Car-to-Car Rear Stationary(CCRs), Car-to-Car Rear Moving (CCRm), and the test object is consistent with Euro-NCAP.

In general, the research on AEB test and the technology of AEB test target vehicle is relatively advanced in foreign countries[5]. However, in recent years, with the rapid development of automotive intelligent networking technology, there have been some new breakthroughs in domestic AEB test research.

In conclusion, none of the AEB test regulations at home and abroad have involved rear-end collision between passenger car and truck with a truck test target. This paper is focused on a new truck target of AEB test. Based on the Future Mobile Traffic Accident Scenario Study/FASS database, which is carried out by the China Automotive Engineering Research Institute, the truck type, size parameters, and color data of the truck end are extracted from the real rear-end traffic accidents between the passenger car and truck. After that, the K-means clustering algorithm is used to cluster the representative colors of the truck end, the reflection properties of the real truck end are measured. According to the above analysis, a new type of truck AEB test target is designed and manufactured, and its feasibility and effectiveness are verified through actual vehicle AEB tests.

2 Accident data basis

2.1 Future Mobile Traffic Accident Scenario Study/FASS

The investigation criterion of accidents in FASS currently are two categories, one is only if at least one four-wheeler involved in the accidents, at least one person involved in the accident is injured, the vehicles in the accident are detained and can be deeply investigated, the accident scene remains unchanged. And the other is only if at least one four-wheeler involved in the accidents, and the accident video can be recorded.

Through accident site investigation, vehicle investigation, accident process video, CAD, PC-CRASH, the following accident information can be get: road and environment information, vehicle basic and damage information, personnel basic and injury information, collision information, etc.

Table.1 Investigation main information

	Main Information
Road&Environment	Road characteristic, environment characteristic, inquiry,marks, etc.
Vehicle	Length, width, year,height, active and passive safety configuration, contact point between VRU and vehicle, vehicle deformation, vehicle damage, etc.
Person	Sex, height, weight, age, injury, etc.
Collision	Collision velocity, angle, overlap, etc.

The collection area includes a variety of road types, such as freeways, highways, urban streets, rural areas and so on. Hence, the data is a good representative sample to study rear-end accidents between passenger car and truck in China.

2.2 Rear-end accident between passenger car and truck in FASS

Until Oct, 2023, there are 9351 accidents in FASS database, and from Figure.1 to Figure.4, we can see that, rear-end accident between passenger car and truck accounts for a large proportion. A total number of 166 passenger car and truck rear-end collision accidents are collected, and among these accidents, the casualty of passengers in passenger cars is very high, which is 84.4%.

Compared with truck, passenger car always has higher speed, lower total mass and lower center of gravity, passenger car is vulnerable to these collision accidents. Under this circumstances, the front of passenger car tends to have a large deformation. More seriously, the passenger car strikes the rear of trucks and may drill into the bottom of the truck, causing serious deformation above the waist line of the passenger car, endangering the safety of the occupants in the passenger car. This type of accident scenario has aroused attention and a lot of research.

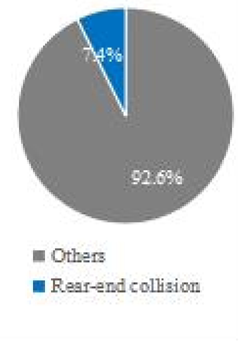


Figure.1 Distribution of accident types

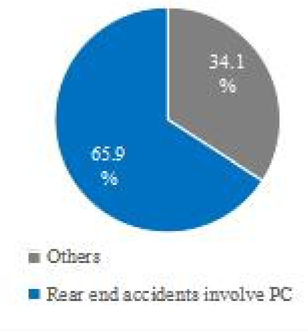


Figure.2 Rear end accidents involving passenger cars(PC)

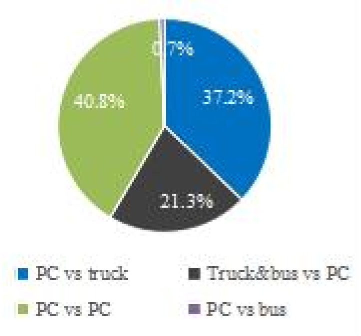


Figure.3 Distribution of rear end accidents involving passenger cars(PC)

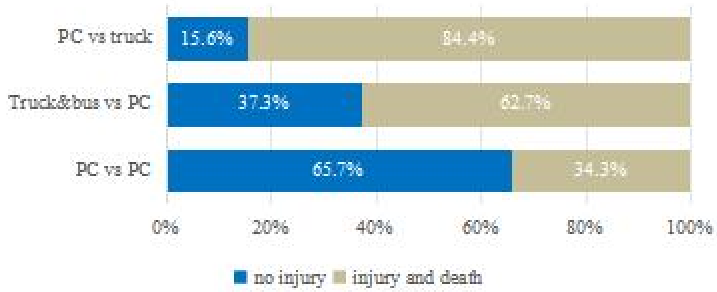


Figure.4 Casualty of occupant in passenger cars(PC) of different accident types

3 Truck target

The requirement of the AEB test truck target is that the characteristics of the truck target by the AEB system sensors during the test should be highly similar to the characteristics of the real truck, and the following design requirements need to be met:

① The size and shape of the truck target can represent the mainstream truck models in road traffic accidents in China.

② The reflection characteristics of the target vehicle is similar to real trucks under conventional onboard sensors, including vision, millimeter wave radar, and LiDAR.

③ The target should resistance to impact, and if the test vehicle collides with the truck target, neither should be damaged.

④ The truck target should be easy to install and use[6][7].

3.1 Appearance characteristics of the target vehicle

According to regulation GA 802-2019 in China, trucks are divided into heavy truck (truck with a total mass of 12000 kg or more), medium truck (truck with a length of more than or equal to 6000 mm, or truck with a total mass of more than or equal to 4500kg and less than 12000 kg), light truck (truck with a length of less than 6000 mm and a total mass of less than 4500kg) and mini truck (truck with length less than or equal to 3500mm and total mass less than or equal to 1800kg). The distribution of the 166 truck types in rear-end collision between passenger car and truck accidents is shown in Figure 5, the proportion of the heavy truck is the highest, accounts for 63.9% in the total trucks, and light truck commits the second highest portion, accounts for 23.5%.

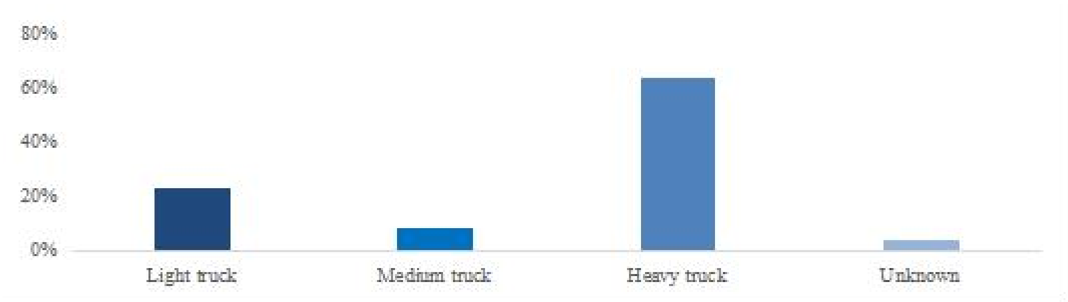


Figure.5 Distribution of truck types

According to the characteristics of the truck end, trucks can be divided into box truck (other types of trucks with modified end characteristics that are consistent with the rear characteristics of box type trucks are also classified as box truck), stake truck, cargo truck, and flat platform truck, as shown in Table.2. Among the 166 accidents, the distribution of truck end with characteristics of box trucks is the highest, at 56.0%.

Table.2 Distribution of truck end characteristics types

Truck end characteristics types	Example	Proportion
Box truck		56.0%
Stake truck		1.8%
Cargo truck		19.9%
Flat platform truck		10.8%
Others&unknown	-	11.4%

We analysis the rear end dimensions of the trucks in these 166 accidents, and combined with the dimensions of mainstream truck models in China, comprehensively design the rear end dimensions of truck targets.

3.2 Color of the target vehicle

3.2.1 Color spaces

Each color can be defined by various numerical values in the color space. The images of trucks involved in accidents is recorded in the FASS database, and we choose the images with truck end in daylight and not under shade,from these images, so we can capture the color values of the pixels truck end. Through clustering algorithms, we can extract color feature values of the truck end in real traffic environment.

The RGB color space is the most used and the most consistent with the human visual system's color perception, but the correlation between the three primary colors is too high. Minor color changes may cause significant fluctuations in several parameters, which limits the use of clustering algorithms in RGB color space. The LUV color space has visual uniformity and is superior to the RGB color space in image processing. This study uses the LUV space obtained from the CIE XYZ space transformation for pixel data processing and analysis, so that the pixel distribution can more clearly display the clustering situation of the samples, and the clustering points of each cluster group are more reasonable. Finally, through conversion, the color data and the final representative color data is presented in RGB space. The conversion from RGB to modified CIE LUV can be accomplished in three steps[8].

①RGB to CIE XYZ

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.412453 & 0.357580 & 0.180423 \\ 0.212671 & 0.715160 & 0.072169 \\ 0.019334 & 0.119193 & 0.950227 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \tag{1}$$

②CIE XYZ to CIE LUV

$$u' = \frac{4X}{X+15Y+3Z} \tag{2}$$

$$v' = \frac{9Y}{X+15Y+3Z} \tag{3}$$

③CIE LUV to modified CIE LUV

$$L^* = 10\sqrt{Y} \tag{4}$$

$$\mathrm{u}^* = 13L^*(u' - u'_n) \tag{5}$$

$$v^* = 13L^*(v' - v'_n) \tag{6}$$

Among them, u', v' are intermediate variable for conversion, the component L^* represents the luminance in the image, u^* and $v^*$are color components.

3.2.2 K-means clustering algorithm

K-means algorithm is used in this paper to cluster and analyze the color data of truck end to obtain the most representative color parameters. And the Silhouette parameter is selected to evaluate how similar an object is to its own cluster compared to other clusters. Its range is from -1 to+1, and a larger value indicates a higher degree of matching relationship between the target and its own cluster, while a lower degree of matching relationship with other clusters. The higher the Silhouette value, the better the clustering results.

Assuming A is a cluster obtained through a clustering algorithm, a (yi) refers to the average degree of dissimilarity between the i-th pixel in cluster A and all other pixels. d (yi, Ci) refers to the average difference between pixel i in cluster A and each pixel in any cluster Ci except for A. Define b (yi)=d (yi, Ci), which is also the minimum value of array d (yi, Ci), that is, C is the cluster with the highest similarity to pixel i. The Silhouette parameter value corresponding to pixel in the cluster is

$$s(y_i) = \frac{b(y_i)-a(y_i)}{max\{a(y_i),b(y_i)\}} \quad (7)$$

By calculating the Silhouette values of each pixel, the Silhouette values of all pixels form a Silhouette array. The average value of the values in the array is calculated to obtain the evaluation index for this cluster segmentation situation[9][10].

This study sets the range of clustering clusters between 2 and 10, and calculates Silhouette values for evaluation, and ultimately selects the cluster with the highest Silhouette value as the target cluster number for the algorithm. As shown in Figure.6, when the number of clusters is 4, the Silhouette value is the highest, which is the optimal number of clusters. That is to say, the final clustering of truck end colors are four colors, red, blue, gray and yellow. Among them, red accounts for the highest proportion of 42.6%, and red is preferred as the truck end color.

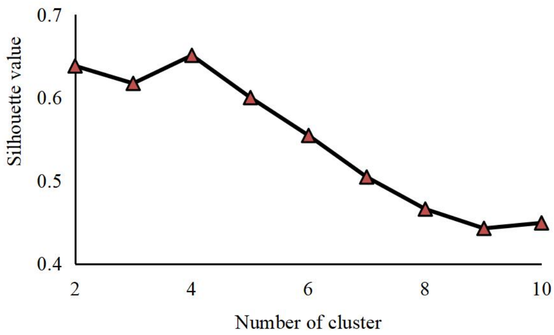


Figure.6 Average silhouette value with different clustering number for truck end

3.3 Reflection characteristics of truck target

Normally, the AEB test target object should have a 3D visual appearance and the millimeter wave radar, Light Detection and Ranging/LiDAR reflection characteristics as the actual vehicle. It must use millimeter wave radar, LiDAR reflective materials that comply with regulations, and the reflective materials must not interfere with the signals sent by GPS installed in the mobile platform vehicle [11]. This paper takes millimeter wave radar, LiDAR and visual recognition characteristics as examples to introduce the process of design and calibrate of the reflection properties for the truck target.

3.3.1 RCS calibration

The onboard millimeter wave radar is one of the core sensors for detecting targets in the ADAS system. The radar distinguishes and classifies target objects by identifying specific millimeter waves reflected by the target object. Radar Cross Section (RCS) is a physical quantity that measures the intensity of the echo generated by a target under radar wave irradiation. In order to design and develop a target that has the same radar emission characteristics as the real truck end, the following measurement calibrations is conducted in this paper [13].

Test site: According to the standards issued by the International Organization for Standardization ISO for RCS test scenarios, there are no other buildings, metals, or other strong radar reflectors that can interfere with the designated radar testing target vehicles in the observable area of the test site. The road surface is completely covered with asphalt or concrete and kept dry.

Test equipment: 77HZ vehicle grade millimeter wave radar, calibration angle sensor, test trucks, and test software.

Test method: ①Calibrate the angle transformer; ②Place the trucks and radar as required, starting from the initial test distance, and measure the RCS of the trucks at each distance every 10m as a node. When the RCS value stabilizes and approaches a certain value, stop testing. Obtain the design channel for the real truck RCS through the above methods. Using the same method, millimeter wave radar tests are conducted on the truck target, and the RCS curve of truck target obtained fell within the range.

3.3.2 LiDAR reflection calibration

LiDAR is a sensor that can accurately detect the position of objects. By emitting a laser signal to the target object, the distance is calculated based on the time difference of the object's reflection signal. The angle between the object and the emitter is determined at the angle of laser emission, thereby the relative relationship between the object and the emitter is obtained.

Test equipment: The calibration of radar reflection needs a spectrometer set, test trucks, and test software.

Test method: ①Select the test area of the vehicle and measure the reflection at two angles using probe brackets at 45°and 90°, respectively. ②After generate the reference spectrum, the relative position between the optical fiber and the probe bracket cannot be moved. ③Measure each group of angles 10 times and calculate the average value. Based on the test results of the same part of each truck, determine the upper and lower limits of LiDAR reflection [12]. Based on the data obtained from the above tests, the LiDAR reflection of the main components at the rear of the truck target has been limited, as suggested in Table.3.

Table.3 LiDAR reflection of the main components at the rear of the truck target

Components	Range
Truck body 45°	10%-70%
Truck body 90°	20%-80%
Tire 45°&90°	＜20%

3.3.3 Visual recognition verification

From near to far, record and take multiple sets of photos of truck targets and actual vehicles at different distances, using multiple universal databases, such as Tencent, Baidu, conduct identification comparison to verify the visual recognition of the truck target. The results indicate that in close range situations, the recognition rates of real vehicle and truck target recognition are all above 90%, and after a long distance, the recognition rate decreases, but the truck target still remains consistent with the real truck.

3.4 Truck target production

According to the above key parameters such as the type, feature size, color, and reflection characteristics of the truck target, the truck target is designed and manufactured. It consists of two main parts: a static bracket and a target vehicle airbag body. The airbag body is fixed together with a drag plate through tightening straps, and the airbag skin is covered with simulated real truck patterns, including the carriage body, reflective strips, headlights, tires, etc, as shown in Figure.7.

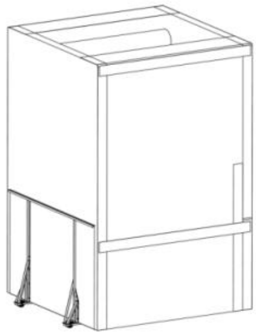


Figure.7 Design of truck target

4 Real vehicle test

4.1 Test condition

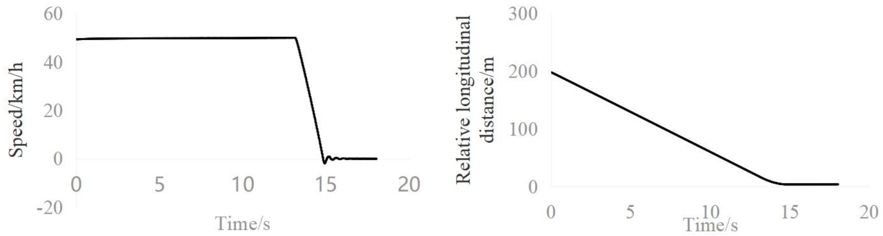
From the FASS database, a typical AEB test condition between passenger car and truck is constructed, which is that the truck is stationary, and the passenger car approaches the rear of the truck at the speed of 50 km/h. The overlap rate of the passenger car is 100%.

4.2 Test preparation

RT base station, test vehicle, truck end balloon vehicle, and operating platform are prepared before the test. The RT base station provides position calibration information to the RT in the test vehicle and the vehicle is equipped with driving robots and pedal robots, which can autonomous during the test vehicle [14][15]. AEB sensor of the test vehicle adopts a combined method of camera and millimeter wave radar, and the camera is installed in the center of the front windshield, while the millimeter wave radar is installed in the vehicle logo during the test. The test is conducted on a closed road test site, with a flat and dry road, daylight, and good lighting conditions.

4.3 Test result

The AEB system test is conducted on the test vehicle at the speed of 50km/h, and the tests are repeated three times.The truck target are all recognized by the test vehicles. The test vehicles successfully braked, avoiding the occurrence of rear-end collision accidents. We can see a test result as shown in Figure.8, the test vehicles has a stable speed driving time of more than 5 seconds, meeting the test conditions. The test uses the inertia sensor RT3002+data acquisition system, RT Range S Target, to record the coordinate value X of the driving direction of the test vehicle (in every tests, the position of the truck target are slightly adjust), the distance from the stopping position of the test vehicle to the truck target is around 1m, indicating that the AEB decision control algorithm of the test vehicle can successfully avoid the collision though can be further optimized in order to ensure a safe parking distance.



a.velocity-time curve b.displacement-time curve

Figure.8 Test result-CCRS velocity at 50km/h

5 Conclusion

Based on the above information, the first AEB test truck target that can represent the characteristics of road traffic accidents in China and accurately reflect the characteristics of real trucks is designed and produced.

(1) This article extracts heavy box trucks and truck end size parameters that can represent the characteristics of road traffic accidents in China based on 166 real rear-end accidents between passenger car and truck in the FASS database, which is carried out by China Automotive Engineering Research Institute.

(2) The K-means algorithm is used to extract the color features of the truck end, and the Silhouette parameter is selected as the evaluation index for the optimal clustering. The optimal number of clusters is 4, with the highest proportion of red. Therefore, the target object at the truck end is red.

(3) Conduct tests to measure the RCS, LiDAR, and visual reflection characteristics of real truck end, and the AEB truck target is covered with PVC material, that can replicates the millimeter wave radar, LiDAR and visual characteristics of the real truck.

(4) Subsequently, optimization will be carried out around the mobility and disassembly of the truck target. Based on a lager sample size of accidents, the analysis of truck end features will be refined in the future.

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