Energy Absorption Analysis of Various Vehicles under Crash Test Simulation

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Abstract

The analysis of energy absorption behavior under crash test simulation is presented as the initial part of the second weight reduction analysis project. The demonstrative crash tests cover the existing front and side impacts with three different segments of the public vehicle models. The objective of the vehicle crash simulation is to investigate the energy absorption in crash tests under the European New Car Assessment Programme (Euro NCAP) criteria. The energy absorption is a critical factor to estimate a safety level of passenger, therefore, the crash performance of three public FE-models of Ford Taurus, Chrysler Neon and Geo Metro is determined using LS-DYNA simulations. Obtained results from the simulations suggest that the segment of the vehicle model has a significant effect not only on the energy absorption but also intrusion of occupant cell.

Keywords*:* analysis of the energy absorption, energy absorption behavior, vehicle crash simulation.

1. Introduction

Energy absorption of a structure is a key aspect to be considered. Furthermore, important issues especially for structure design, vehicle weight and passenger cell intrusion are compared to represent the vehicle crashworthiness. Typically, lightweight vehicles could contribute to reduction of fuel consumption in urban traffic. These vehicles normally cannot provide safety measure under impact condition, unless lightweight vehicles are designed to absorb energy comparable to larger vehicles. Therefore, the objective of this research is to investigate energy absorption of various vehicle segments under the second weight reduction analysis project at Forschungs gesellschaft Kraftfahrwesen mbH (Innovative Vehicle Attribute Engineering), Aachen, Germany. Major purpose of the whole project is the examination of the characteristics of passenger cell structure as well as energy absorption and intrusion behavior of the models after collision. Within this research, particularly the representation of the mechanical characteristics of the passenger cell structure and component structure under dynamic loads is investigated for three different types of public models. Consequently, the load cases of front crash with Offset Deformation Barrier (ODB) and side crash with Mobile Deformable Barrier (MDB) are proposed. In order to compare the public vehicle models, it is necessary to evaluate and control relevant vehicle characteristics in test procedure. The relevant aspects of the front and side impacts are:

- Good structure interaction
- Energy absorption behaviour
- Passenger cell intrusion

Controlling the energy absorption time histories and the intrusion time histories of impacting vehicles are the main objective in the entire duration impact.

2. Overview of Test Regulations

Generally a car should pass all tests before it is released into the market. One of them is the crash test which simulates the accidental situations, in which the interaction of the occupants and the car body is measured. To satisfy different consumers in Europe market, the European New Car Assessment Programme (Euro NCAP) is established.

This test program includes front and side impacts with deformable barrier together with a side pole impact. For the Euro NCAP frontal crash as shown in Fig. 1, the vehicle is travelling at 64 km/h before impacting deformable barrier (ODB) with 40 % overlap offset.

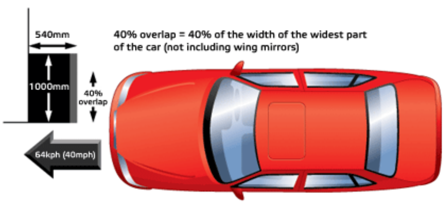


Fig. 1 Test condition of the Euro NCAP front impact with ODB [1]

It is necessary to perform the side-impact test because a car body does not have a significant crumple zone to absorb the crash energy in this area. As shown in Fig. 2, a collision between the vehicle and a mobile deformable barrier (MDB) is carried out. The barrier travels at 50 km/h which has a mass of 950 kg.

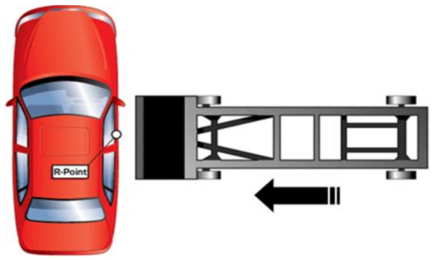


Fig. 2 Test Condition of the Euro NCAP side impact with MDB [1]

The impact needs to take place with a zero degree angle and the evaluation of results must consider the amount of B-pillar intrusion as well as its deformed shape. In vehicle design especially for its structure, the H-point, which is relative to an occupant's hip, is a significant position. Also particularly the pivot point between the torso and upper leg of the body which is relative to the floor of the vehicle is considered [1].

2.1 Crashworthiness

Over the years, the body structures especially in progressive crush zone have been evolved in order to absorb the crash kinetic energy through vehicle material during plastic deformations. The vehicle bodies are manufactured and designed in order to protect occupants by maintaining integrity of the passenger cell by controlling the crash deceleration pulse to fall below the upper limit of human tolerance. Therefore, the target of crashworthiness is dealing with an optimized automobile structure that controls vehicle deformation areas in order to maintain the adequate space in passenger cell. The residual crash energy can be managed by the restraint systems to minimize crash loads transferred to the vehicle occupants as shown in Fig. 3.

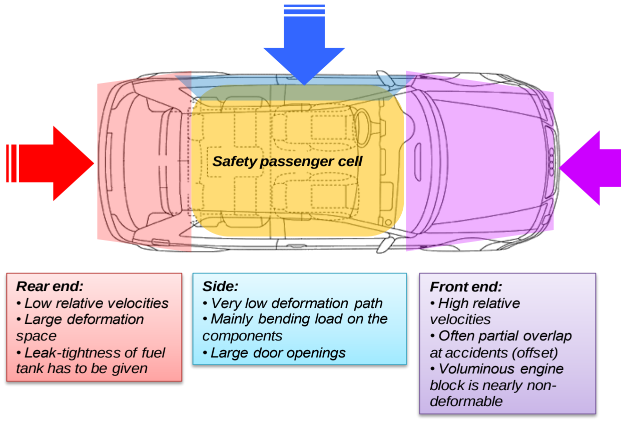


Fig. 3 Comparison of deformation areas front, side and rear impact [2]

Briefly, the vehicle structure should yield a deceleration pulse that satisfies the following crashworthiness requirements:

- Deformable front structure with crumple zones to absorb the crash kinetic energy resulting from frontal collisions by plastic deformation and to prevent intrusion into the occupant compartment.
- Appropriately designed side structures and doors to minimise intrusion in side impact and prevent doors from opening due to crash loads.
- Strong compartment structure for passenger protection

Therefore, automotive design relies on a combination of standard laboratory tests, proving ground evaluations and analysis e.g. to meet the safety targets.

The law of conservation of energy explains that energy inside a system cannot be created or destroyed, and it can be transferred from one form into another without changing the total amount of energy. Considering mechanical systems, such as the vehicle systems, the absorbed work or internal energy of a system cannot exceed the work input. In theory, internal energy is equal to the work (E) done by external forces on the system, which is equal to the product of the exerted force (F) and the distance (d) through which the force moves:

$$E = F \cdot d \qquad (1)$$

The kinetic energy (E_k), which is the energy of motion of a rigid body, is expressed by the following relationship:

$$E_k = \frac{1}{2} \cdot m \cdot v^2 + \frac{1}{2} \cdot I \cdot \omega^2 \qquad (2)$$

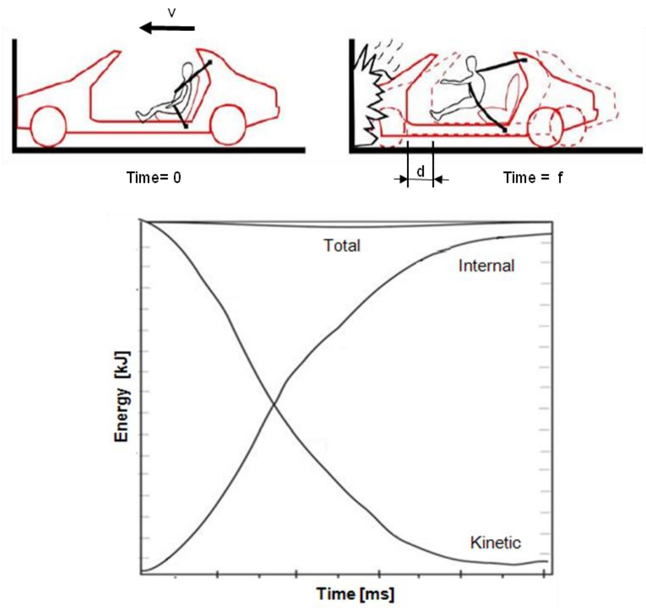


Fig. 4 Example of internal, kinetic and total energy during frontal impact [3]

During the impact of a vehicle, its kinetic energy is predominantly transformed into plastic deformation of the respective structures, for which the internal energy can be calculated using equation (1). To simplify the concept, the energy of a head-on vehicle impact against a rigid barrier is provided as example in Fig.4. The rigid barrier is fixed during the impact so its kinetic energy is constantly zero. Due to the rigid body definition, it does not deform and absorb energy. Therefore, the energy of the vehicle is equal to the energy of whole system. This means that the kinetic energy of vehicle is absorbed by itself during impact time [3].

After the impact, the remaining kinetic energy is attributed to the fact that there is a start of rotation (around the ODB barrier) of the vehicle. The energy absorbed by the vehicle is also converted in sliding interface energy (better known as contact energy) of frictional forces. Other forms of absorbed energies are stonewall and hourglass energies. The amount of these energies is shown in Fig.5 as "other energies".

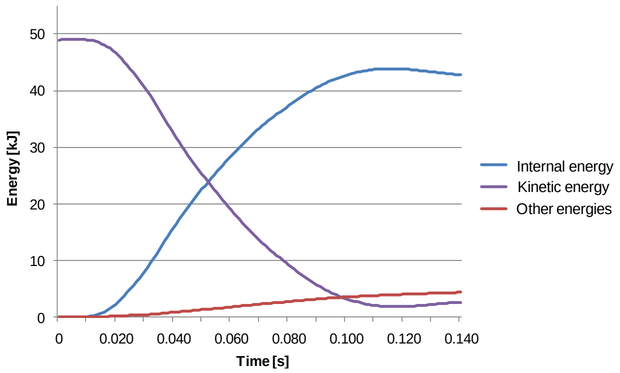


Fig. 5 Usual behavior of energies of the vehicle models during impact time

3. Methodology

The energy absorption behaviors for three public vehicle FE-models are analysed regarding the front and side impacts. For this aim, the FE-models of Ford Taurus, Chrysler Neon and Geo Metro are chosen as shown in Fig. 6.

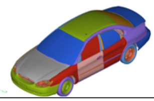
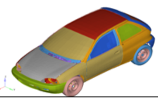
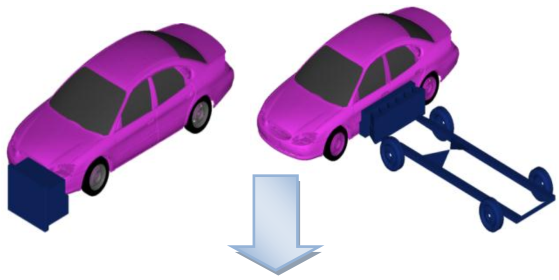
Models	Class Size	Weight	Node	Shell Element
Ford Taurus 	Mid-size car	1,625 kg	936,786 nodes	795,667 elements
Chrysler Neon 	Compact car	1,314 kg	283,859 nodes	267,786 elements
Geo Metro 	Subcompact car	546 kg	200,350 nodes	191,980 elements

Fig. 6 Vehicle data for FE analysis

The vehicle FE-models include most of important parts except a specific part in the engine bay, specific parts in the interior, rear seats and detailed parts in the front module. The load cases for the analysis of the energy absorption behavior are illustrated in Fig. 7.



Evaluation criteria:

- Deformation of the body structure
- Analysis and comparison of the energy absorptions
- Analysis and comparison of the intrusions

Fig. 7 Euro NCAP ODB and Euro NCAP MDB

The preliminary simulation of front and side crash of the complete vehicle is carried out in accordance with the Euro NCAP standard. The possibly high velocities of front and side crashes generate a massive impact to passenger. Thus, the evaluation criteria of body structure regarding ideal energy absorption are very important.

4. Results and Discussion

The total amount of internal energy to be absorbed by the chosen vehicle models is calculated from the kinetic energy of a non-rotating mass. Therefore, the internal energy from those vehicles is 256.7 kJ, 207.6 kJ and 86 kJ for Ford Taurus, Chryler Neon and Geo Metro respectively. The simulation of the complete vehicle is carried out and the results from initial position to final deformation of body are shown in Fig. 8-10.

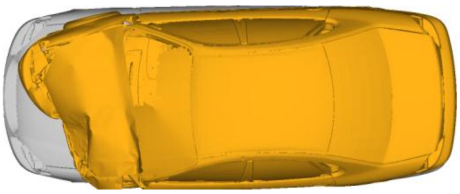


Fig. 8 Top view of Ford Taurus overlapping pre (gray) and post (orange) impact

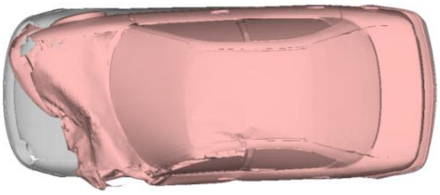


Fig. 9 Top view of Chrysler Neon overlapping pre (gray) and post (pink) impact

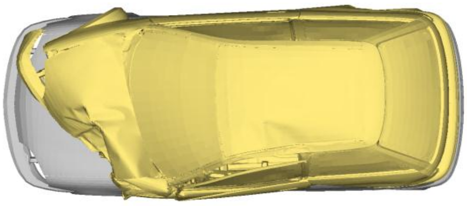


Fig. 10 Top view of Geo Metro overlapping pre (gray) and post (yellow) impact

The intrusion into the passenger compartment is calculated after the crash, when the vehicle is permanently deformed and considered the main source of output data. Crash performance of public models is illustrated in Fig 11. The intrusion results of three different models are compared with each other.

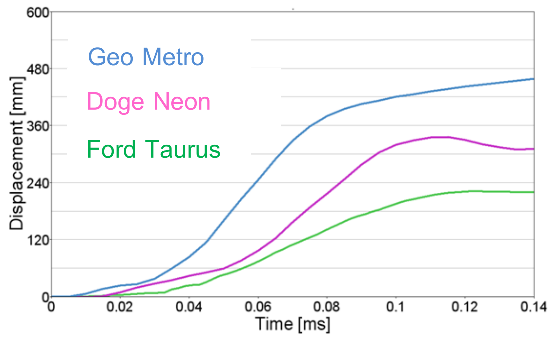


Fig. 11 Intrusion in Euro NCAP frontal impact test

For the simulation results, the energy absorbed by three different types of the FE-models are illustrated in Fig. 12

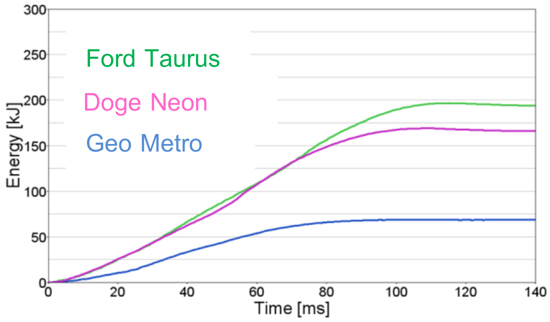


Fig. 12 Internal Energy absorbed in front impact test under Euro NCAP standard

Figure 13-18 show the comparative structural deformation after the three crash tests. Detail shots illustrate the bonnet, windshield and upper longitudinal member intrusion. Pictures also illustrated the frontal deformation pattern against the aluminum honeycomb barrier and demonstrated not only the vehicle comparative stiffness but also intrusion performance.

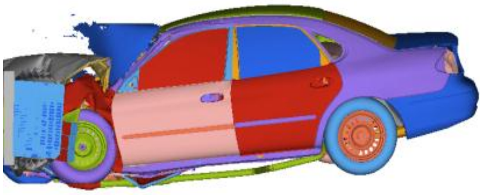


Fig. 13 Ford Taurus frontal characteristic

Fig. 14 Chrysler Neon frontal characteristic

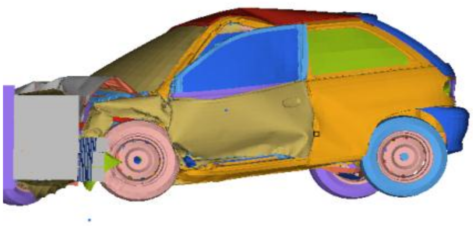


Fig. 15 Geo Metro frontal characteristic

The results of primary position and final deformation of side body structure are shown in pictures below.

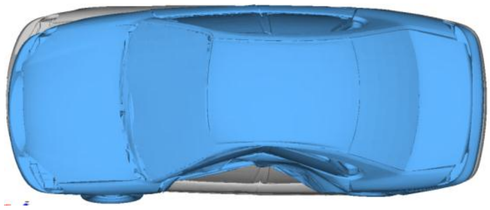


Fig. 16 Top view of Ford Taurus overlapping pre (gray) and post (blue) impact

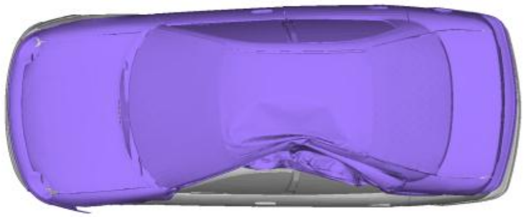


Fig. 17 Top view of Chrysler Neon overlapping pre (gray) and post (purple) impact

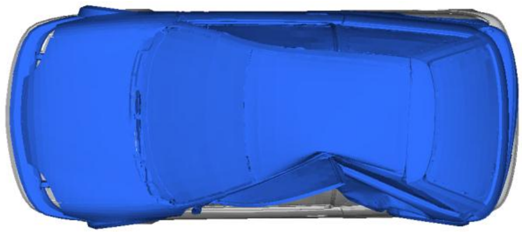


Fig. 18 Top view of Geo Metro overlapping pre (gray) and post (cerulean) impact

For the simulation results, the energy absorbed by different size of the public vehicle FE-models is illustrated in Fig.19.

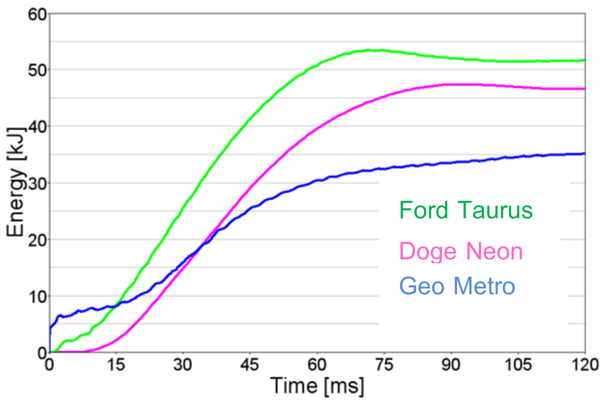


Fig. 19 Energy absorbed in Euro NCAP side impact test

Side impact parametric studies have been carried out using full vehicle finite element models. The purpose of this work is to clarify the effect of the geometry, energy absorption and intrusion on the impacted car's structure in different weight and this will help to classify car structure characteristics which will improve compatibility with the different segments of vehicle models.

The crash performance of public models is illustrated in Fig. 20. The intrusions are compared for the three different types of vehicle models.

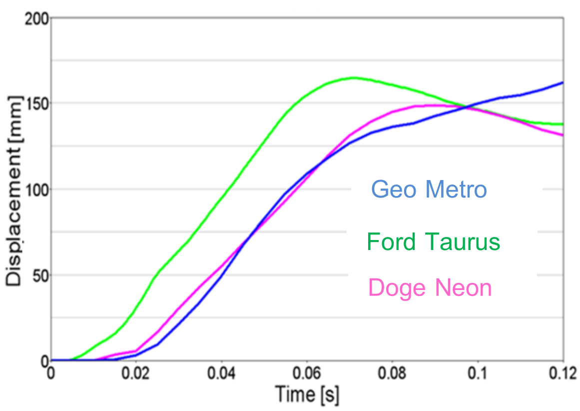


Fig. 20 Intrusions in Euro NCAP side impact test

5. Conclusion

The task of this research is to analyse the energy absorption behaviors of different vehicle bodies as the beginning part of the second weight reduction analysis project. Therefore, vehicle crash simulations have been carried out to demonstrate the results in terms of energy absorption in crash tests under Euro NCAP condition.

The obtained results from the simulations suggest that the weight and size of the vehicle models have a significant effect on the energy absorption and intrusions. If the front or rear end of the vehicle 'A' is long enough to crush twice as much as vehicle 'B' in a crash at the same velocity, then occupants of vehicle 'A' will experience half as much force as the occupants in vehicle 'B', because it takes twice of stop time. Using energy absorption and intrusion analysis approach reveals the behavior of vehicle structures in comparison of different types of vehicles under impact tests. At the same time, this strategy has led to optimal results in terms of the overall integrity and occupant protection performance of the vehicle.

6. Acknowledgement

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7. References

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