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Crashworthiness of Car Interior Door Trims in Side Impact- A Review

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***Abstract*— Many investigations of real world accidents, crash test results & simulation studies have established that in side crashes of passenger cars, thoracic & pelvic injuries of occupants are in large part caused by occupants impact against the interior side of the vehicle, primarily the door and other intruding side structures. Crashworthiness deals primarily with the "second collision", in which the driver and passengers collide against the interior of the vehicle. Objective of the crashworthiness is to minimize the injury potential to occupant. To avoid the occupant injury it is important to absorb the whole kinetic energy both of the vehicle and of the occupants. Crashworthiness features are the part of the structure which helps to minimize occupant injuries, to prevent ejection from the vehicle, to reduce the risk of fire. Crashworthiness evaluation is ascertained by a combination of tests and analytical methods. This paper will mainly focus on the study of the crashworthiness of door trim, its crashworthiness features & assessment tests.**

Index Terms— **Door trim, Side impact, Crashworthiness features, Crashworthiness tests**

NOMENCLATURE

IRTE : Institute of Road Traffic Education
NCAP : New Car Assessment Programs
NHTSA: National Highway Traffic Safety Administration
FMVSS: Federal Motor Vehicle Safety Standard
ECE-R : Economic Commission for Europe - Regulation
Vcmax : Viscous Criterion
PSFP: Pelvic Symptom Free Period
APF: Abdominal Peak Force
MDB : Mobile Deformable Barrier
BIW: Body in White
SID: Side Impact Dummy
SINCAP: Side Impact New Car Assessment Programs
ES2: Euro SID 2
WG13 : Working Group 13
IIHS: Insurance Institute for Highway Safety
T&P SAB: Thorax & Pelvis Side Airbag
DACIT: Door and Chassis-frame Integration Technology
ANCAP: Australian NCAP
CIREN: Crash Injury Research and Engineering Network
USDOT: United States Department of Transportation
NASS/CDS: National Automotive Sampling System
PMHS: Post Mortem Human Subjects
ATD: Anthropomorphic Test Devices
HYGE & VIA : System to Simulate the Effects of a Collision in Acceleration
GM: General Motors

I. INTRODUCTION

In the recent years, the focus of safety research and vehicle design is increased in the safety characteristics of motor-vehicle. Currently India is the fifth largest producer in the world of passenger cars but new independent crash tests show why automotive industries should use internationally accepted safety standards. The Global

NCAP crash test results of Nissan’s Datsun Go and Maruti-Suzuki’s Swift demonstrate a high risk of life-threatening injuries as both cars receiving zero-star safety rating for their adult occupant protection. These risks would be significantly reduced if the cars had to comply with the UN test regulation for frontal and side impact.

Mr. Rohit Baluja, the President of Institute of Road Traffic Education (IRTE) complimented the Ministry of Road Transport & Highways for their initiative with the automobile industries to start the process of the Indian NCAP as well as towards generating a regulatory structure. Though, Mr. Baluja laid emphasis that USA initiated the process of having an NCAP in 1979, and most automobile manufacturing countries have followed same. He also added that currently India is far behind schedule and must complete both the regulatory and NCAP consumer information process not later than 2016. The Bharat New Vehicle Safety Assessment Program is a proposed New Car Assessment Program for India. It is the 10th NCAP in the world and is being set up by IRTE and Federal Government of India. AS per 10th NCAP, an offset front crash, side and rear impact tests will be mandatory by 2017.

Considering vehicle safety, the crash event mainly classified into the pre-crash and the post-crash stage. At the pre-crash stage, crash occurrence is determined by the product of crash exposure and crash propensity. In general, crash exposure represents the amount of opportunities for crashes to which a vehicle is exposed. Crash propensity is the conditional probability of the vehicle being involved in a crash given a unit of exposure. While crash exposure is generally approximated by distance travelled, crash propensity is supposed to be associated more with human factors, that is, driver behaviour or performance. At the post-crash stage, crash severity is of more concern, which is dependent on the crashworthiness (i.e. self protective capacity) of the struck vehicle and the crash aggressivity (i.e. the hazardousness that the subject vehicle imposes on the counterpart vehicle(s) involved in the same crash, with other external factors being controlled) of the striking vehicle [1].

Approximately forty percent of all crashes are side impacts. [2]. Over thirteen thousand deaths, due to side impact, occurred during 1998 in the United States alone[3]. Many investigations of real world accidents studies have established that in side crashes of passenger cars, injuries of occupants are in large part caused by occupants impact against the interior side of the vehicle, primarily the door and other intruding side structures. To avoid the occupant injury it is important to absorb the whole kinetic energy both of the vehicle and of the occupants [4].

II. CRASH STANDARDS

The worldwide activities to improve passive safety in side impact started in the 1980’s with research work at the National Highway Traffic Safety Administration (NHTSA). A static side intrusion test was developed. This became the Federal Motor Vehicle Safety Standard No. 214 (FMVSS 214). In 1990 FMVSS 214 was extended to include the dynamic crabbed barrier test. This was the first side impact regulation that included a side impact dummy (SID) and was enacted in 1993, with a phase in of three years. In 1997 NHTSA included a lateral impact consumer test known as SINCAP. This was an additional test to the frontal NCAP. Instead of the FMVSS214 speed of 53 km/h, the rating test is completed with a velocity of 61 km/h. The rating is based on acceleration measured in the thorax region of the dummy. More than 40 cars were tested in the first year; none obtained the best score of 5 stars. In the following year two cars achieved a 5 star rating for the driver. Following a further 2 years the first passenger car improved to point of earning a double 5 star rating (for the first two seating rows). Now a days, in European countries most cars have a 4 to 5 star rating and only one car in 2004 earned only a two star rating. Parallel in Europe the European Enhanced Vehicle Safety Committee Working Group 13; (EEVC WG13) started their research activities to create a European wide regulation ECE-R95. This included a new European barrier and a new generation of dummy, EuroSID1 (ES1). The implementation date for new type approvals was October 1998[5].

During 1997 prior to this regulation taking effect, Euro NCAP decided to implement the research work of the EEVC WG13 into their program. The more stringent targets at Euro NCAP, especially rib intrusion and abdominal forces, were set at a higher level than current European legislation. Most models earned less than 10 out of 16 points. Today more than half of all cars tested achieve the maximum 16 points for the side impact barrier test. In 1995 NHTSA issued an amendment to FMVSS 201 to include upper interior head impact protection using a ‘Free Motion Head Form’ (FMH). During 1998 a further final rule was issued, this allowed a reduced impact speed for

FMH testing in the area where a head protection was packaged. The head protection system's effectiveness needed to be proved through a dynamic pole crash test. This enabled car manufacturers to implement side impact curtains whilst still meeting the upper interior head protection requirements. For this test the Side Impact Dummy was redeveloped in the neck and head area and called SIDHIII. This dummy was also integrated in the SINCAP procedure. Euro NCAP implemented the lateral pole test procedure in the year 2000 similar to the US standard, but using the ES1 dummy. The test is voluntary and awards two extra points towards the side impact score. With the implementation of the pole impact, Euro NCAP changed the highest possible score from four to five stars. Today many manufacturers are able to achieve the Euro NCAP goals for pole impact (even with the new 2002 head acceleration limits and the modifier for improper airbag deployment). Many manufacturers now build head protection airbags into their vehicles as standard. This provides the best possible protection for customers whilst also achieving a 5 star rating. During 2003 an EEVC proposal for an updated barrier was implemented into the existing ECE-R95 requirement. This was closely followed in 2004 with a change to the dummy from ES1 to Euro SID 2 (ES2). ES2 was shown to have a slightly higher bio-fidelity rating compared to ES1. Again Euro NCAP decided to implement these changes from WG13 into the rating in 2003. This was four years before the changes became mandatory for new vehicle type approvals [5].

In June 2003 the Insurance Institute for Highway Safety focused on the predominately North American issue of heavy SUVs involved in side impact. A new barrier was designed to duplicate the front-end stiffness and overall size of a typical North American SUV (Sport Utility Vehicle). The five percentile female dummy SIDIIs (SID IIs) was used as the occupant for both seat rows. Current research work for regulations in the next three to seven years includes the upgrade of the US regulation FMVSS214. A notice of proposed rulemaking was published by NHTSA in spring 2004 and proposes four full-scale side impact tests instead of the current, one Since model year 1997, all passenger cars in the U.S. have been required to comply with FMVSS No. 214, a safety standard that mandates a minimum level of side crash protection for near side occupants [5].

III. LITERATURE REVIEW

Javier Luzon-Narro et al. [2], presented six simultaneous innovative occupant near side lateral impact protection concepts including a dynamic door, high-volume side airbag, a large external airbag that covers doors, sill and B-pillar of the struck vehicle and other concepts for increasing the distance between the occupant and the door panel (active armrest, inflatable door beam and moving seat). All systems are based on pre crash detection of the impact and are activated as soon as 80ms before the impact. This paper also details the task of integrating these systems into a vehicle using FE models, sled tests, and full scale crash tests.

John Townsend et al. [3], discussed The design and development of the side impact modular door system for different size vehicles with and without DACIT. In addition, he also presented the five stars rating achieved during several side impact crash tests simulating Sport Utility Vehicles hitting mid-size vehicles, equipped with the developed modular door system. This paper presents a proprietary side impact protective door system within the space between the outer skin of a car door and the occupant, which will be as efficient as that already standard in frontal impact. A variation in safety and structural performance of the developed door system can be achieved by integrating the structural modular door with the vehicle body, using a patented integration system known as Door and Chassis-frame Integration Technology (DACIT). Unlike the traditional doors, that are just suspended weights, the modular door is truly structural and therefore adds strength to the vehicle body. When DACIT is used with the door system the vehicle door becomes part of the overall vehicle structure.

Gustavo Zini et al. [4], indicated some feasible innovations that may lead to a better side impact protection, pointing out some aspects that can be developed thoroughly within the corresponding settings and using the appropriate resources. The mentioned innovations analysed from a general and synergistic point of view, using basic engineering and physics principles. Simulations performed using a simplified model consisting on a single-mass/inelastic spring system. The protection offered by current safety devices analyzed, segmented into three groups (pre-impact, impact and post-impact).

Jonathan Rupp et al. [7], developed a new injury risk curves for the hip by analyzing forces associated with structural failure of the hip. In motor-vehicle crash testing, anthropomorphic test devices (ATDs), which are also known as crash-test dummies, act as human surrogates. As such they are designed to replicate the kinematics and deformations of similarly sized humans that are produced by vehicle deceleration and restraint system loading and to assess the potential for injury to a vehicle occupant in a staged motor-vehicle crash or a crash simulated by a sled-impact test. Injury potential is assessed on a body region level (e.g., knee–thigh–hip complex) by measuring the force, moment, deformation, and/or acceleration experienced by the body region and then comparing these measurements to injury risk curves. Injury risk curves are relationships between a parameter describing the level of applied mechanical loading measured by the crash-test dummy (e.g., peak force applied to the knee or peak anterior-to-posterior chest compression) and the risk of injury to a body region.

Aekbote et al. [8], described the development of a new component test methodology concept for simulating NHTSA side impact, to evaluate the performance of door subsystems, trim panels and possible safety countermeasures (foam padding, side airbags, etc.). The concept was developed using MADYMO software and the model was validated with a DOT-SID dummy. Moreover, this method is not restricted to NHTSA side impact, but can be also be used for simulating the European procedure, with some modifications. This method uses a combination of HYGE and VIA decelerator to achieve the desired door velocity profile from onset of crash event until door dummy separation, and also takes into account the various other factors such as the door/B pillar-dummy contact velocity, door compliance, and shape of intruding side structure, seat-to-door interaction and initial door-dummy distance. This method is can be used for side airbag evaluation, by simulating the close-in velocity and distance between the side structure and dummy.

Yih-Charng Deng et al. [9], has developed the detailed finite element model of the human thorax for impact injury studies. The model has realistic geometric and material representation of the rib age, heart and lungs. A modelling procedure was developed to identify suitable material constants for the ribs to account for its composition of cortical bone and trabecular bone. Constitutive equations proposed in the literature for describing the mechanical behavior of the heart muscle and the lung parachema were implemented in the Dyna3D program for this study. The model was validated against cadaver thorax test results for both the frontal and lateral impact. Good correlation was achieved in both conditions for the force and the deflection responses.

Thanapon Chotika et al. [10], demonstrated crash tests which cover the existing front and side impacts with three different segments of the public vehicle models. 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. Herve Guillemot et al. [11], proposed the first corridor including the behaviour of the pelvic bony structure up to the level of injury. An experimental study of the pelvic bony structure subjected to static and dynamic loads was carried out in order to document its biomechanical behaviour and its injury threshold. 22 pelvises were tested under side loading conditions. Displacements, applied force, and local strains of the pubic rami were obtained.

IV. OVERVIEW OF CRASHWORTHINESS

First used in the aerospace industry in the early 1950’s, the term “crashworthiness” provided a measure of the ability of a structure and any of its components to protect the occupants in survivable crashes. Similarly, in the automotive industry, crashworthiness connotes a measure of the vehicle’s structural ability to plastically deform and yet maintain a sufficient survival space for its occupants in crashes involving reasonable deceleration loads. Crashworthiness deals primarily with the "second collision", in which the driver and passengers collide against the interior of the vehicle. Crashworthiness evaluation is ascertained by a combination of tests and analytical methods [21].

A. Crashworthiness Requirements

The vehicle structure should be sufficiently stiff in bending and torsion for proper ride and handling. It should minimize high frequency fore-aft vibrations that give rise to harshness. In addition, the structure should yield a deceleration pulse that satisfies the following requirements [21].

i. Deformable, yet stiff, front structures with crumple zones to absorb the crash kinetic energy resulting from Frontal collisions by plastic deformation and prevent intrusion into the occupant compartment, especially in case of offset crashes and collisions with narrow objects such as trees. Short vehicle front ends, driven by styling considerations, present a challenging task to the crashworthiness engineer

ii. Deformable rear structure to maintain integrity of the rear passenger compartment and protect the fuel tank.
iii. Properly designed side structures and doors to minimize intrusion in side impact and prevent doors from Opening due to crash loads.
iv. Strong roof structure for rollover protection.
v. Properly designed restraint systems that work in harmony with the vehicle structure to provide the occupant with optimal ride down and protection in different interior spaces and trims.
vi. Accommodate various chassis designs for different power train locations and drive configurations.

B. Criteria Used To Determine The Crashworthiness of The Structure

i. Deformation patterns of the vehicle structure.
ii. Acceleration experienced by the vehicle during an impact.
iii. Probability of injury predicted by human body models.

Injury probability is defined using criteria, which are mechanical parameters (e.g., force, acceleration, or deformation) that correlate with injury risk. A common injury criterion is the Head injury criterion (HIC).

C. Crashworthiness Tests

In spite of the tremendous progress achieved in crashworthiness simulations of vehicle structures from components to full-scale vehicles, using the latest techniques in computational mechanics and super computers, final crashworthiness assessment still relies on laboratory tests. This is especially true in vehicle certification [21].

There are three categories of tests: component tests, sled tests, and full-scale barrier impacts. The complexity of the test and associated variables increases from component to full-scale tests. This may cause a decline in test repeatability – a reality that may not be realized from the mathematical models. The component test determines the dynamic and/or quasi-static response to loading of an isolated component. These component tests are crucial in identifying the crush mode and energy absorption capacity. Understanding their performance is also essential to the development of prototype substructures and mathematical models [21].

In a sled test, engineers use a vehicle buck representing the passenger compartment with all or some of its interior components such as the seat, instrument panel, steering system, seat belts, and air bags. Mechanical surrogates of humans (anthropomorphic test devices - “dummies”) or cadaver subjects are seated in the buck to simulate a driver and/or passenger and subjected to dynamic loads, similar to a vehicle deceleration-time pulse, to evaluate the occupant response in a frontal impact or side impact. The primary objective of a sled test is evaluation of the restraints. This is accomplished by high-speed photography of the dummy kinematics. In addition, various sensors located in the dummy and on the restraints monitor the forces and moments to help determine the impact severity and the effectiveness of the restraint system in reducing loads transferred to the occupant [21].

The typical full-scale barrier test involves collision of a guided vehicle, propelled into a barrier at a predetermined initial velocity and angle. Typically, a barrier test uses a complete vehicle. To evaluate individual substructures, a sled test can be equally effective, especially in evaluation of the restraint systems [21].

Testing is both time consuming and expensive, particularly at the early stages in Vehicle Crashworthiness and Occupant Protection vehicle development, where only prototypes are available. To ensure the crashworthiness and compliance with U.S. and international regulations of a vehicle platform, the manufacturer may test more than 100 prototype vehicles, with each early prototype costing $400,000 to $750,000. For decades, design engineers have expressed the need to simulate the crash event using mathematical models. Accurate and robust analytical tools using state-of-the-art in computational mechanics and computer hardware are indispensable for crash simulations [21].

To meet ever-increasing safety demands, especially those associated with air bags, vehicle design has evolved into a complementary mix of testing and mathematical modelling. The expected performance and the design stage determine the type of test and level of test complexity. Whether assessing crashworthiness by a test, by a computer simulation, or by a combination of both, the ultimate objective is to determine the potential for human injury due to exposure to real world crash conditions. Unfortunately, each real world crash is a unique event, and therefore attempting to duplicate all real world crash conditions is a formidable task that is both time-consuming and expensive. Accordingly, engineers use selective laboratory crash modes that appear to be most relevant to reducing injuries and saving human lives [21].

1. *Car to Car Side Impact*

The second most important crash configuration after frontal impact is car to car side impact. Fig. 1 below shows the ECE 95 barrier test setup. Euro NCAP simulates this type of crash by having a mobile deformable barrier (MDB) impact the driver's door at 50 km/h. The injury protection is assessed by a side impact test dummy, in the driver's seat. Although it is difficult to judge the level of protection provided from the extent of intrusion, control of how the car side intrudes is important. Through the programme, Euro NCAP has seen large improvements in side impact performance. The provision of side impact airbags has helped. It is now normal for the cars tested by Euro NCAP to be fitted with side impact airbags.

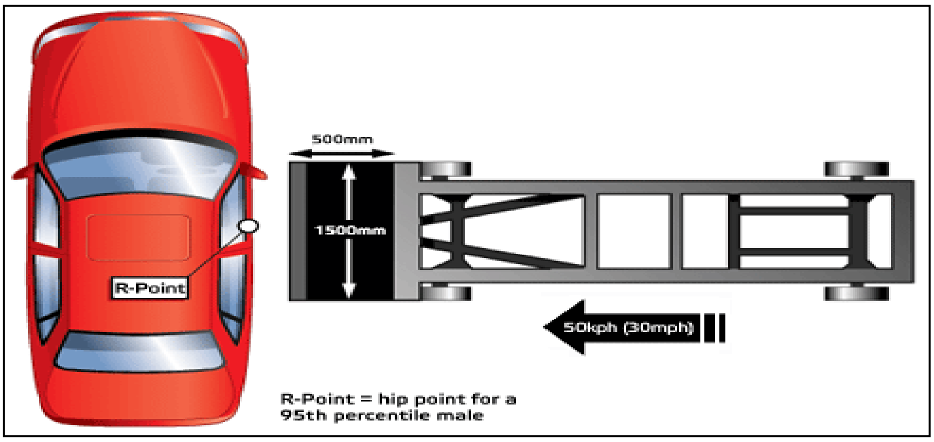

Fig. 1 Car to car side impact – ECE 95 barrier test

2. *Pole Side Impact*

Accident patterns vary from country to country within Europe, but approximately a quarter of all serious-to-fatal injuries happen in side impact collisions. Many of these injuries occur when one car runs into the side of another or into a fixed narrow object such as a tree or pole. To encourage manufacturers to fit head protection devices, pole test may be performed, where such safety features are fitted. Fig. 2 below shows the ECE 95 barrier test setup. In the test, the car tested is propelled sideways at 29kph (18mph) into a rigid pole. The pole is relatively narrow, so there is major penetration into the side of the car. In an impact without the head protecting airbag, a driver's head could hit the pole with sufficient force to cause a fatal head injury. Typically a head injury criterion of 5000 is possible, five times that which indicates the likelihood of serious brain injury. In contrast, the head injury criterion in these new crash tests with a head protection airbag is around 100 to 300, well below the injury reference value.

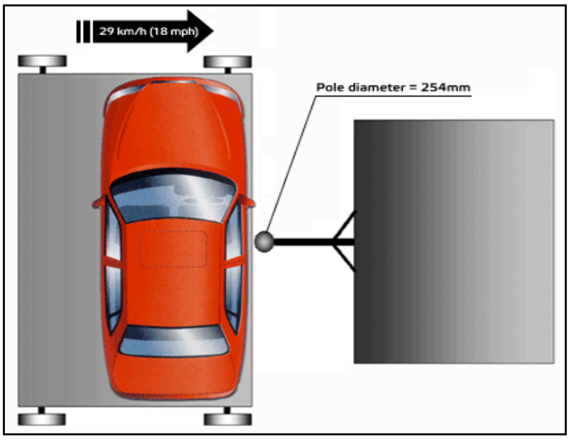

Fig. 2 Pole side impact

Before 2009, Euro NCAP has allowed the manufacturer to perform a pole test to demonstrate the efficacy of the head protection system where this safety feature is fitted. The assessment focused on the head only and the result was used to augment the side impact score achieved in the MDB side impact test. As of 2009, the pole test has become mandatory and now includes assessments on other critical body regions that might be affected such as chest and abdomen.

V. CRASHWORTHINESS OF DOOR TRIM IN SIDE IMPACT

A. Need for crashworthiness in Side impact

In recent years, side-impact crashes in the US between SUVs (Sports Utility Vehicle) or LTVs (Light Trucks & Vans) and passenger cars are increasing, resulting in a high number of serious or fatal injuries. It has become an important task to reduce body injury levels, not only to the head, but to the thorax and pelvis as well. One way to protect the occupant's thorax and pelvis in side-impact crash is T&P SAB (Thorax & Pelvis Side Airbag) [16].

Side impact collision is one of the toughest safety challenges facing the Auto Industry today. Over thirteen thousand deaths, due to side impact, occurred during 1998 in the United States alone [3].

New Car Assessment Programs (NCAP) in Australia, Europe, Japan and the USA are giving increasing attention to the protection of vehicle occupants in side impact crashes [12].

Car manufacturers are more and more concerned with the protection of the occupants in lateral impacts. Field accident analysis dealing with automotive side collisions suggests that the pelvis is very vulnerable, but there is a lack of knowledge of the behavior of the pelvic bony structure and of its biomechanical tolerance. This knowledge however is essential in order to optimize protection devices and car structures with regard to the security of the occupants [11].

Pelvic fractures account for about 12% of injuries suffered in a side impact Compared to patients in MVAs without pelvic injury, those with pelvic fracture have more severe injuries and higher mortality rates. A collapsible console and a seat track which allows lateral displacement of the seat may help to reduce pelvic injury in side impact crashes [17].

B. Passenger Car interior door trim elements

Crashworthiness deals primarily with the "second collision", in which the driver and passengers collide against the interior of the vehicle. In side impact the occupant mainly collides with the door trim panel which is made of plastic to absorb the energy with the least reactive forces to avoid the injury to occupant. To understand the crashworthiness of door trim in side impact it is important to first understand the elements & structures of the door trim.

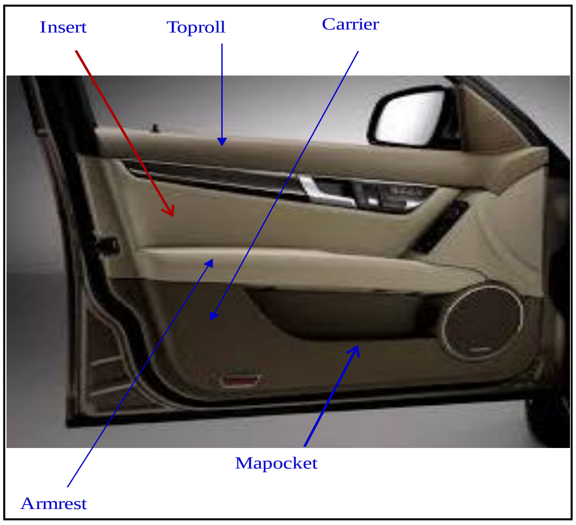

Fig. 3 Elements of Door Trim

The door trim is generally divided into 5 sections or parts, namely top roll, insert, armrest, main carrier & Ma-pocket as shown in the Fig. 3 shown below. Thorax & pelvis portion of occupant generally comes below the armrest, hence the region below the armrest have more space from the body in white structure to absorb the energy.

C. Subsystem Side Impact Test or Drop Test

To study & improve the crashworthiness of the door trim panel the subsystem side crash test or drop test is done on the door trim assembly. This test is based on the second collision between occupant & dummy. This test is similar to the sled test, in which engineers use a vehicle buck representing the passenger compartment with its interior components. Instead of Mechanical surrogates of humans (anthropomorphic test devices - “dummies”) or cadaver subjects like in sled test here steel impactor’s as shown in Fig. 4 are used to simulate a driver or passenger and subjected to dynamic loads, similar to a vehicle velocity-time pulse, to evaluate the occupant response in a side impact [13].

The velocity of the impactor is ranging from 3m/s -5 m/s and impact energy is 50-90J for abdomen & 300-600J for PELVIS based on the which dummy to be considered. The primary objective of a drop test is monitor the forces and moments to help determine the impact severity and the effectiveness of the door trim system in reducing loads transferred to the occupant. CAE simulations are generally carried out for optimization of the door trim stiffness for minimum forces to be transfer to occupant.

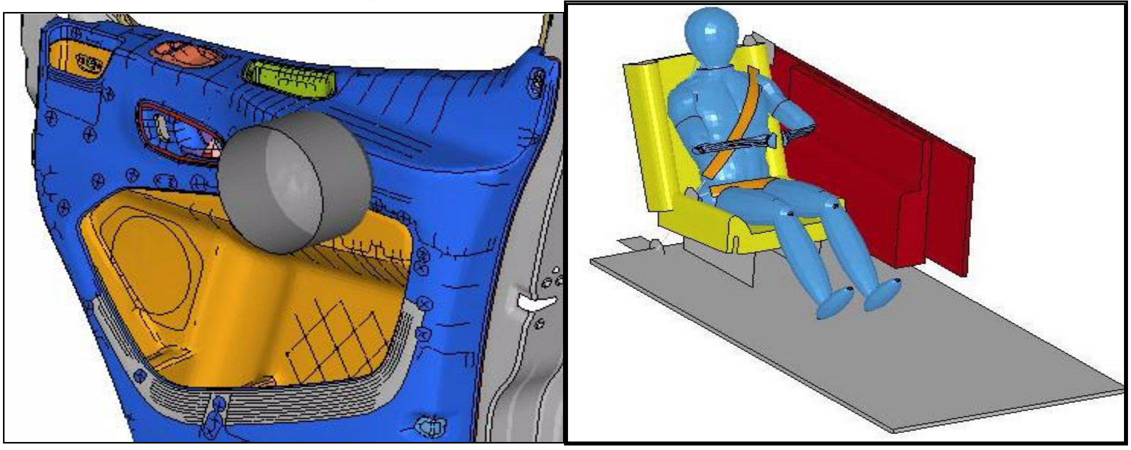

Fig. 4 Drop trim test setup & Occupant representation by impactors [14]

D. Biomechanics & Subsystem Side Impact Requirements

Extensive study has been done on the biomechanics of human body and critical injury parameters have been decided. The force deflection characteristics are generally evaluated in component & sled test.
The dummy used in ECE-R 95 is EUROSID dummy and its injury criteria cover maximum acceleration level to the head, rib deflection limits and peak forces to the abdomen and pelvis are shown in table 2 [15].

Table 1 EUROSID dummy injury criteria [15]

Head	HPC	< 1000
Thorax	Deflection	< 42mm
	VCmax	< 1 m/s
Pelvis	PSFP	< 6.0 KN
Abdomen	APF	< 2.5KN

A force–deflection response from the tests resulted in hip fracture (i.e. structural failure of hip) is shown in Fig. 5 below. The fracture force is around 6.5KN. To mimic the fundamental aspect of a car-to-car impact and study the injury mechanisms the thorax model was struck laterally as shown in Fig. 6. Fig. 7 illustrates a comparison between the Thorax FE model and the cadaver test for the force and deflection responses with respect to the time [9].

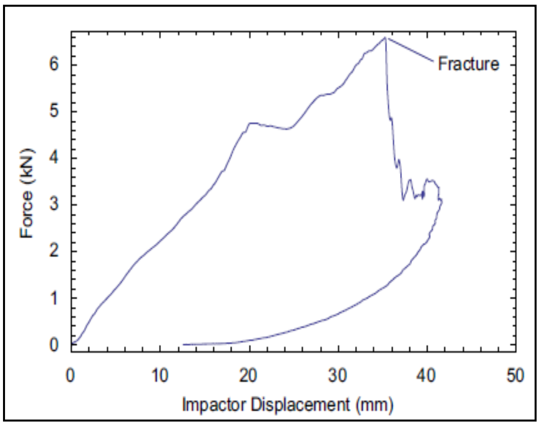

Fig. 5 Typical applied force vs. impactor displacement curve [7]

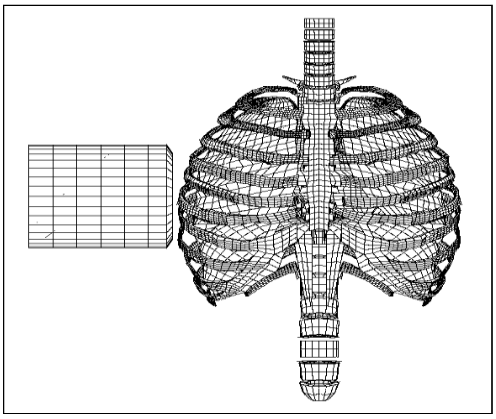

Fig. 6 Thorax lateral injury test Setup [9]

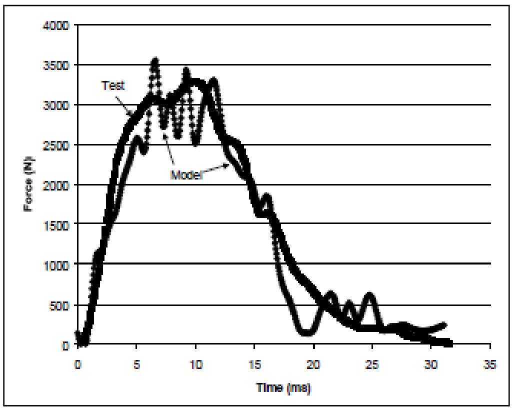

Fig. 7 (a) Force-time history [9]

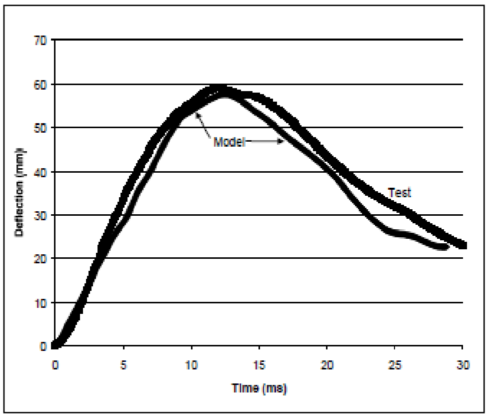

Fig. 7 (b) Deflection-time history [9]

E. Crashworthiness Features

These are the features from the structure which helps to minimize occupant injuries, to prevent ejection from the vehicle, to reduce the risk of fire. This includes below features.

i. Three point seat belts
ii. Airbags
iii. crumple zones

1. Three Point Seat Belts

Invented by Volvo engineer Nils Bohlin and patented in 1959, three point seat belts have saved more than one million lives. Wearing the belt reduces the risk of death or serious injury to drivers by about 50%. In a crash unbelted occupants will move at the same speed as the vehicle before the collision and will hit the interior structures (steering wheel etc). Using a belt stops this ‘catapult’ effect and distributes the force of the crash over the stronger parts of the body, whilst preventing ejection from the vehicle or impact with other occupants.

Wearing seat belts first became mandatory in Australia’s State of Victoria in 1970 and is now commonly applied around the world. Three point belts are now being integrated with other passive safety devices and use ‘pre-tensioners’ that pull the belt tight just before the air bag deploys and the impact occurs. Fig. 8 shows a three point seatbelt which are the most important Crashworthiness feature in cars.

Fig. 8 Three Point seatbelt

2. Airbags

Originally invented by John Hetrick a retired US engineer in 1953, air bags work as a safety cushion to automatically protect vehicle occupants in a crash. In order to pass the most common vehicle crash test standards for front and side impact it is necessary for manufacturers to install air bags. Air bags are a Supplementary restraint system (SRS). They are intended to be used in conjunction with a seat belt and not as alternative. Fig. 9 shows an inflated airbag in the typical CAE simulation.

The first car with an air bag was the Oldsmobile Toronado in 1973. Ford made them standard equipment in 1990. Volvo introduced the first side impact system in 1995 and in 2006 Honda developed the first air bag system for motorcycles.

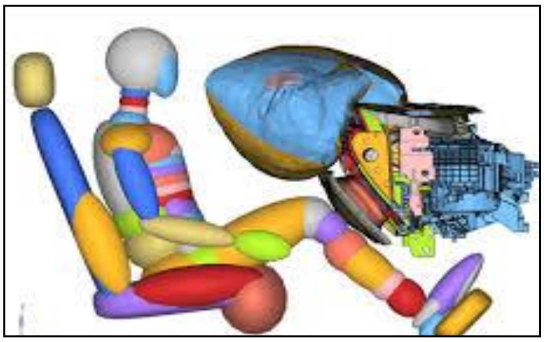

Fig. 9 Airbag

3. *Crumple Zones*

Invented by Mercedes-Benz engineer Bela Barenyi in the 1950s (Fig. 11), crumple zones are the most basic feature of passive safety design. The task of a crumple zone is to absorb the kinetic energy released in a crash to protect occupants. Barenyi showed that by controlling the deformation of vehicle energy could be directed away from the occupant cabin. By placing occupants in a rigid cell, surrounded by softer vehicle sections designed to collapse in a crash, the shock of the impact is directed away from the vulnerable humans in the vehicle.

The main difficulty in designing for side impact collisions is the limited crumple zone between the impacting vehicle and the impacted occupant [3].
Crumple zones were first applied in 1959 to the Mercedes-Benz 220 which are shown in Fig. 10 below with green colour.
Fig. 12 below shows a door trim stiffness requirement for crashworthiness.

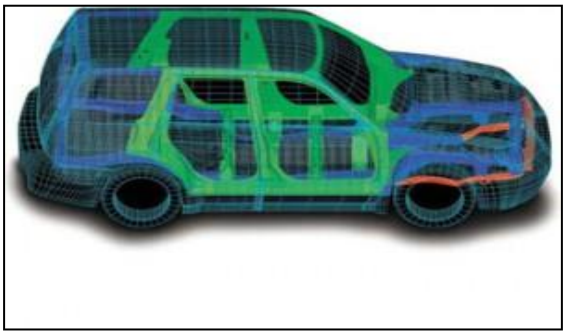

Fig. 10 Mercedes-Benz 220

Fig. 11 Bela Barenyi with model of crumple zone

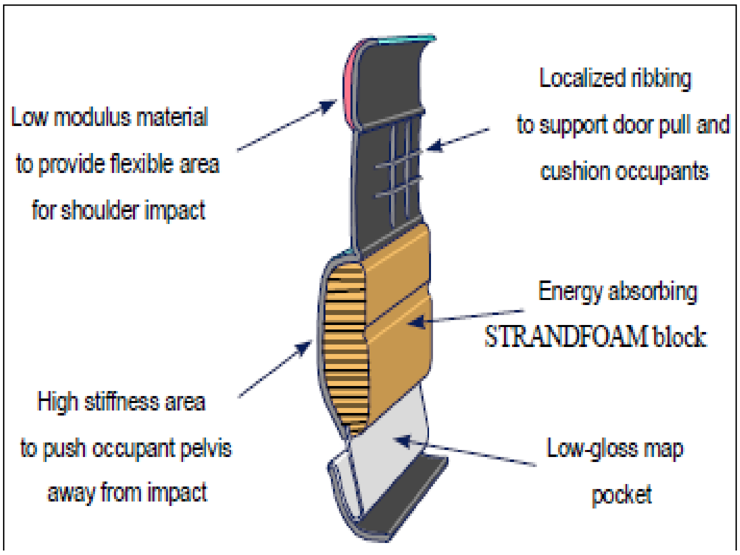

Fig. 12 Door trim section with stiffness requirement [18]

A good structural behaviour is necessary but not sufficient to perform good results in side impact. A proper control of padding stiffness is very important especially for abdomen & Pelvis protection [19].

Strengthening the passenger compartment improve occupant protection, especially adding pusher foam is significantly lowering the injury values in SINCAP [15]. One of the countermeasures that greatly improve the energy dissipation in the car interior is the addition of the energy absorbing padding material in the door area. NHTSA, among the others has conducted tests with & without padding in the doors and found that the addition of padding reduces thoracic injury potential by about 30 percent in many production cars tested using the FMVSS 214 test [20]. Fig. 13 below shows foam padding & Plastic padding used for pelvis region.

Fig. 13 Foam padding & plastic Padding

VI. SUMMARY

The safety characteristics of motor-vehicles now have a prominent focus of both safety research and vehicle design worldwide. Global NCAP which is a non profit organization started recently in United Kingdom is taking initiative to spread the car safety awareness worldwide. They also tested the India's 7 famous car in 2014 as per the euro NCAP regulations & all of them were failed to fulfil the basic requirements of regulation. After these test results by global NCAP, Indian Ministry of Road Transport & Highways took initiative with the automobile industry to start the process of the Indian NCAP as well as towards framing a regulatory structure & planning to complete the regulatory and NCAP consumer information process not later than 2016. Now it is been mandatory that all vehicles must satisfies crash standards by 2017.

Real world vehicle collisions are unique dynamic events but for the purpose of body development, safety experts classify vehicle collisions as frontal, side, rear or rollover crashes. Different Studies shown that almost 40% of the real life crashes are side crashes and these are also the most severe compared to other types. USA and Europe has also developed the regulations & NCAP for side impact which is also mandatory.

FMVSS has divided the car safety in two phases, active & passive safety. Objective of active safety is crash avoidance & that of passive safety is crashworthiness. Active safety includes the design of the equipments which helps to avoid the crash event like Braking (ABS), electronic stability control (ESC). Crashworthiness includes the design of equipments or structure which helps to minimize risk of injury to occupants, by absorbing impact energy and ensuring a survival space. Seatbelts, airbag & crumple zones are the commonly used for better crashworthiness.

Car interior Door trims plays a major role in the crashworthiness in side impact. Component level dynamic tests are generally carried out to evaluate the crashworthiness of the door trim in side impact. The main difficulty in designing for crashworthiness of side impact collisions is the limited crumple zone between the impacting vehicle and the impacted occupant. The foam or crash padding in the door trim is most useful to absorb the maximum energy with the minimum packaging space to avoid injuries. Side airbags are also widely used now days in USA & European cars.

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