ISSN 2395-1621

A Case Study on Design and Analysis of Automotive Body for Crashworthiness

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ABSTRACT

The term "crashworthiness" provides a measure of the ability of a structure and any of its components to protect the occupants in survivable crashes .Crashworthiness evaluation is ascertained by a combination of tests and analytical methods. This Project consists of understanding the basic theory and principles of crashworthiness and case study of bonnet .Case study includes modeling and analysis of bonnet(sheet metal part) for crash. Various tests such as Full Frontal impact and Offset Deformable Barrier are used to analyze the bonnet. Crash analysis is carried out by using ANSYS Software. Crash behavior of the bonnet is analyzed and its crash performance is optimized by changing stiffness of the bonnet through geometry and material changes. The results are oriented towards achieving the best crash performance in least weight.

Keywords— **Crashworthiness, Full Frontal impact, Offset Deformable Barrier**

ARTICLE INFO

Article History

Received :28th Septmber 2015

Received in revised form :

6th October 2015

Accepted : 8thOctober , 2015

Published online :

12th October 2015

I. INTRODUCTION

Safety is the most important aspect for designing automobiles . In automobile design, crash analysis is the most important engineering processes in developing a high quality safety in the vehicle. Computer simulation technologies have greatly endorsed the safety, reliability, and comfort of today's automobiles. This significant achievement was realized with the advanced software and powerful computers that have been available in the last decades. The primary concern for drivers and passengers is safety. Manufacturers have responded to this key concern and expectation with an increasing number of regulations. Although the details may vary slightly from country to country, the fundamental requirements are almost similar. Safety features like Airbags, Antilock Braking Systems etc are used to protect occupants during crash. A less tangible feature that cannot easily be seen by drivers and passengers is the crash response behavior. In a well-designed automobile, the car body and various components are the protective layer for the occupants of the vehicle. They serve as the crumpling zone to absorb the energy of impact. The traditional approach involves multiple iterations of design, evaluation, and prototype and crash tests analysis. The process is time consuming and expensive. The availability of high performance computers and crash simulation software has reformed the process. Instead of relying on experimental validations, the safety design process is supplemented with computer simulation to evaluate the design. Since the inception of crash simulation, the product cycle of a new automobile has been reduced by half and the resultant vehicle is compatibly more safer, better and comfortable.

Requirements defined by the legal protocols for vehicle homologation (e.g. ECE in Europe and FMVSS in the United States) were established. Some of the consumer and insurance associations have been active for decades in establishing improved safety procedures for testing and rating vehicles. During the past few years, factors such as increased consumer awareness of safety related issues, easier access to published test results on Internet, use of crash rating as *leitmotiv* of advertising campaigns have induced OEMs to consider safety target rating early in the vehicle design program.

After a brief overview of three of the main passenger vehicle rating systems, i.e., Euro-NCAP, US-NCAP, and

IIHS, focusing on occupant safety, publicly available data will be analyzed. Trends and gaps will be identified, leading to a description of potential improvements achievable by optimizing the energy management and load control capability.

II. NHTSA/CRASHWORTHINESS

The National Highway Traffic Safety Administration (NHTSA), under the U.S Department of Transportation, was established by the Highway Safety Act of 1970, as the successor to the National Highway Safety Bureau, to carry out safety programs under the National Traffic and Motor Vehicle Safety Act of 1966 and the Highway Safety Act of 1966. The Vehicle Safety Act has subsequently been recorded under Title 49 of the U.S. Code in Chapter 301, Motor Vehicle Safety. NHTSA also carries out customer programs established by the Motor Vehicle information and cost savings Act of 1972, Which has been recorded in various chapters under Title 49. NHTSA is responsible for reducing deaths, injuries and economic losses resulting from motor vehicle crashes. This is accomplished by setting and enforcing safety performance standards for motor vehicles and motor vehicle equipment, and through grants to state and local governments to enable them to conduct effective local highway safety programs. NHTSA investigates safety defects in motor vehicles, sets and enforces fuel economy standards, helps states and a local community reduce the threat of drunk drivers, promote the use of safety belts, child safety seats and airbags. Investigate odometer fraud, establish and enforce vehicle anti-theft regulations and provides consumer information on motor vehicle safety topics. NHTSA also conducts research on driver behavior and traffic safety, to develop the most efficient and effective means of bringing about safety improvements.

III. PROTOCOLS AND RATING

As far as occupant safety is concerned there are three main programs leading passenger vehicles safety
Improvements in Europe and in the United States (USA):

- US-NCAP (New Car Assessment Program in USA)
- Euro-NCAP (New Car Assessment Program in European countries)
- IIHS (Insurance Institute for Highway Safety in USA)

US-NCAP: TESTING PROTOCOL AND RATING

The New Car Assessment Program (NCAP) was initiated in the United States in 1978. Beginning with 1994 model year (MY) vehicle production, the National Highway Traffic Safety Administration (NHTSA) developed and adopted a simplified nonnumeric format using stars. At the beginning NCAP provided consumers with a measure of the relative safety potential of vehicles in frontal crashes. NCAP now supplies consumers with important comprehensive information, which includes frontal and side crash test results since 1997, to aid them in their vehicle purchase decisions. The ultimate goal of NCAP is to improve occupant safety by providing market incentives to vehicle manufacturers who voluntarily design their vehicles to better protect occupants in a crash and are less susceptible to rollover rather than by regulatory directives. Different model year vehicles with different level of safety equipment beyond standard equipment are purchased at dealers and then tested. Recently, US-NCAP started assessing rollover vehicle performance and child occupant protection. However, results from these tests do not yet contribute to the final vehicle rating.

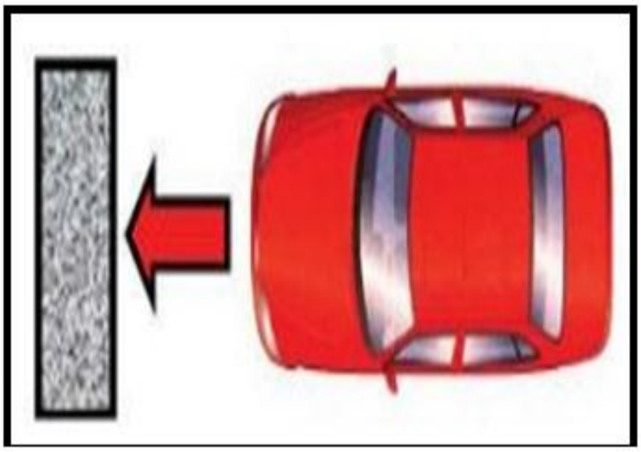


Fig.1 – USNCAP Frontal Impact Test Set-Up

US-NCAP: Frontal Impact Rating

- Among all the reported Hybrid III readings only head HIC15 and chest acceleration contribute to the star rating. A combined probability of an AIS4 injury (Pcombined) is calculated based on the head (Phead) and chest (Pchest) Injury Risk Function:
- Pcombined = Phead + Pchest - Phead * Pchest

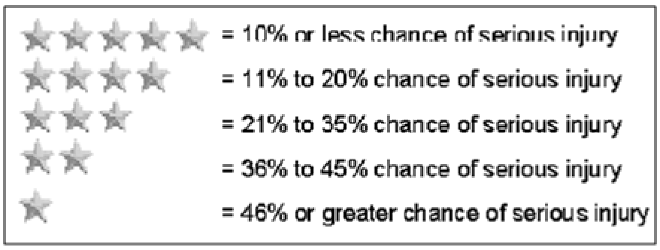


Fig.2: USNCAP Frontal Impact Rating

EURO-NCAP: TESTING PROTOCOL AND RATING

Established in 1997 and now backed by five European governments, the European Commission and motoring consumer organizations in every European Union country, Euro-NCAP acts as the catalyst for encouraging safety improvements to new car design. It further provides consumers with a realistic and independent assessment of the safety performance of some of the most popular cars sold in Europe. Cars for testing and evaluation are purchased at dealers. Only production versions with standard safety equipment, i.e., air bags, are rated. Euro-NCAP rates vehicles for occupant safety as well as pedestrian safety according to EEVC WG17. During the tests, child seats are fitted in the car to assess child occupant protection, but this does not contribute to final safety rating.

Euro-NCAP Frontal Impact Test

To assess occupant safety Euro-NCAP prescribes a frontal impact test, i.e., 40% Offset Deformable Barrier (ODB), and a side impact barrier test. The frontal impact (FI) test performed by Euro-NCAP is based on the European ECE-R96 frontal impact protocol with increased impact speed, i.e., 64km/h vs. 56km/h. 50th percentile male HYBRID III dummies are fitted into the driver and front passenger seat. Both dummies are belted during the test .

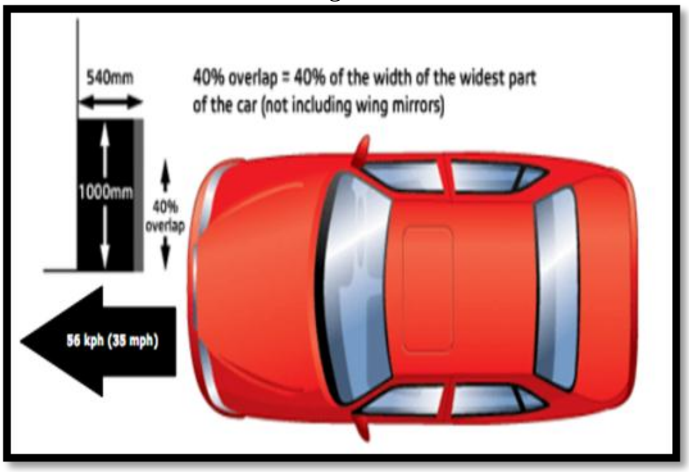


Fig.3 – Euro-NCAP Frontal Impact Test Set-Up (RH drive)

Euro-NCAP Occupant Rating

In order to assess the likelihood of injury, the dummy body is divided into separate regions:
Head / Neck / Chest / Knee, Femur and Pelvis /Lower Leg / Foot / Ankle (Frontal Impact). For each body region at least one bio-mechanical parameter is measured and has well defined Upper Limit (UL) and Lower Limit (LL). If all the values in a body region meet the Lower Limit, four points are awarded to that region; for regions above the Upper Limit (=EEVC), zero points are awarded; regions with results between the two Limits score points directly related to their position between the Upper and LowerLimit. The protection provided for each body region is represented by a color, based on the points awarded (Good = green, Adequate = yellow, Marginal = orange, Weak = brown, Poor = red).

TABLE 1. – Euro-NCAP Frontal Impact Bio-mechanical Limits

	Lower Limit	Upper Limit
HEAD		
HIC$_{36}$	650	1000
Acc$_{3ms}$ [g]	72	88
NECK		
Shear [kN]	1.9 (0ms); 1.2 (25-35ms); 1.1 (45ms)	3.1 (0ms); 1.5 (25-35ms); 1.1 (45ms)
Tension [kN]	2.7 (0ms); 2.3 (35ms); 1.1 (60ms)	3.3 (0ms); 2.9 (35ms); 1.1 (60ms)
Extension [Nm]	42	57
CHEST		
Compression [mm]	22	50
Viscous Criterion [m/s]	0.5	1.0
KNEE, FEMUR and PELVIS		
Femur Compression [kN]	3.8	9.07 (0ms); 7.56 (10ms)
Knee Slider Compressive Displ. [mm]	6	15
Lower Leg		
Tibia Index	0.4	1.3
Tibia Compression [kN]	2	8
Foot/Ankle		
Brake Pedal Rearward Displ. [mm]	100	200

IIHS OCCUPANT TESTING: PROTOCOL AND RATING

Established more then 30 years ago, the Insurance Institute for Highway Safety (IIHS) focuses on countermeasures aimed at all three factors that relate to motor vehicle crashes, i.e., human, vehicular, and environmental, and on interventions that can occur before, during, and after crashes to reduce losses. IIHS performs low-speed bumper crash tests, head restraints tests and frontal offset crash tests, rates the tested vehicles and publishes the results.

IIHS: Frontal Impact Test

The Frontal Impact test performed by IIHS is based on the European ECE-R96 protocol with increased impact speed, i.e.,64km/h vs. 56km/h. A 50th percentile male HYBRID III dummy is fitted and belted into the driver seat. The tested vehicle impacts an offset deformable barrier with 40% overlap.

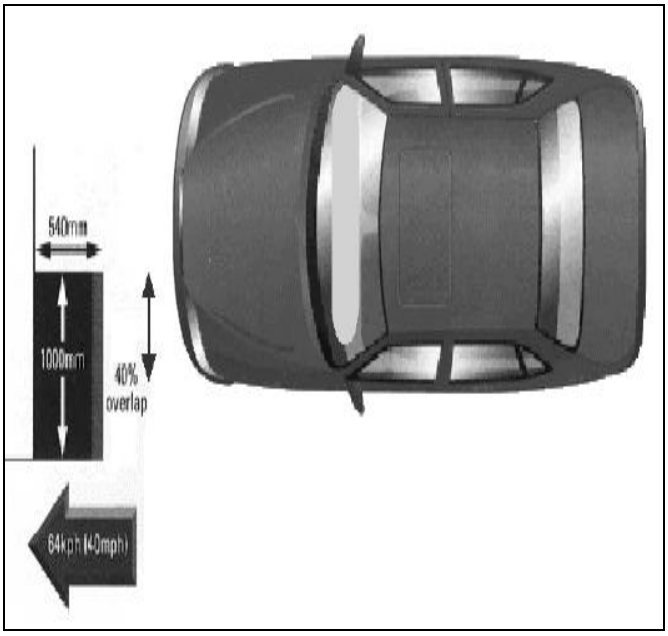


Fig.4: IIHS Frontal Impact Test Set-Up

IIHS Frontal Impact ODB Occupant Rating

IIHS attributes an overall evaluation to each vehicle tested. The three factors assessed in the frontal offset crash test, e.g., structural performance, injury measures, and restraints - dummy kinematics, determine each vehicle overall crashworthiness evaluation. The order in which vehicles are listed (overall evaluation) depends primarily on crash test performance, with head restraint and bumper evaluations influencing the rankings of vehicles with similar performance.

Considering more in detail the contributors to IIHS ODB rating:

Structure - safety cage (BIW): structural performance is based on measurements indicating the amount and pattern of intrusion into the occupant compartment during the offset test. This assessment indicates how well the front-end crush zone manages the energy delivered during the crash event, and how well the safety cage limits the intrusion into the driver space. Performance of the structure and safety cage is a major component of each vehicle overall evaluation.

Injury measures: it is obtained from a 50th percentile male Hybrid III dummy belted in the driver seat. Injury measures are used to determine the likelihood that drivers have sustained injury to various body regions. Measures are recorded for the head, neck, chest, and both legs and feet. Like structural performance, this assessment also is a major component of each vehicle overall evaluation.

Restraints and dummy kinematics (movement): significant injury risk can result from undesirable dummy kinematics, e.g. partial ejection from the occupant compartment, in the absence of high injury measures. This aspect of performance involves how safety belts, airbags, steering columns, head restraints, and other aspects of the restraint systems interact to control dummy movement. Although this assessment is important, it does not contribute as much as structural performance or injury measures to each vehicle overall evaluation. To rate structural and safety cage performance the permanent deflection of seven points on the vehicle interior is measured. The final rating reflects the band with the most measures, e.g., maximum one level above the worst measurement (Fig1.5, Good = green, Acceptable = yellow, Marginal = orange, Poor = red). Based on qualitative observations the structural rating can be lowered one level from the rating suggested by the intrusion measurements

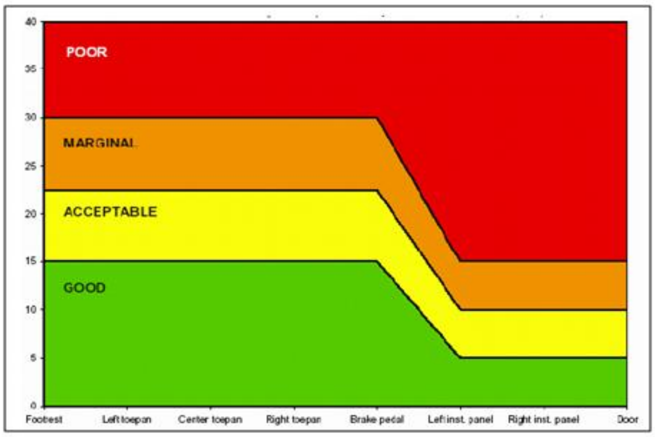


Fig 5:IIHS ODB, Structural Safety Cage Rating

To rate injury measures the dummy body is divided into four separate regions with different injury parameters

- Head and Neck
- Chest
- Left Leg and Foot
- Right Leg and Foot

The overall injury rating for anybody region is the lowest rating scored for any injury parameter within that region

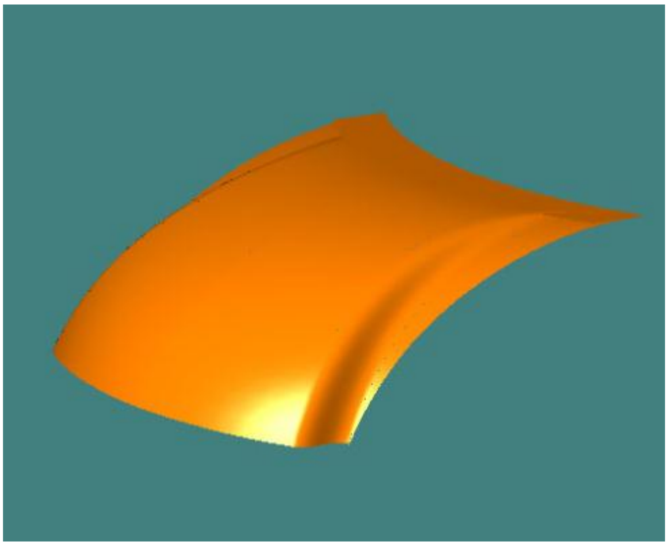
TABLE.2: IIHS ODB Injury Parameters Rating

	Good	Acceptable	Marginal	Poor
HEAD& NECK				
HIC_{15}	<560	560-700	700–840	>840
N_{ij}	<0.8	0.8-1.0	1.0-1.2	>1.2
Neck Axial Tension [kN]	<2.6	2.6-3.3	3.3-4.0	>4.0
Neck Comp. [kN]	<3.2	3.2-4.0	4.0-4.8	>4.8
CHEST				
Thoracic Spine Acc_{3ms} [g]	<60	60-75	75-90	>90
Sternum Defl. [mm]	<50	50-60	60-75	>75
Sternum Defl. Rate [m/s]	<6.6	6.6-8.2	8.2-9.8	>9.8
Viscous Criteria [m/s]	<0.8	0.8-1.0	1.0-1.2	>1.2
LEG&FOOT (left-right)				
Femur Axial Force* [kN]	<7.3	7.3-9.1	9.1-10.9	>10.9
Tibia-femur Displ* [mm]	<12	12-15	15-18	>18
Tibia Index (upper, lower)**	<0.8	0.8-1.0	1.0-1.2	>1.2
Tibia Axial Force* [kN]	<4.0	4.0-6.0	6.0-8.0	>8.0
Foot Acc [g]	<150	150-200	200-260	>260

IV. CRASH ANALYSIS OF BONNET

A] SOLID MODELLING:

Modelling of BONNET is done using CATIA SOFTWARE. CATIA V5 is Geometric modelling software developed by Dassault systems. It is the commercial computer program used in product development solutions for wide variety of industries, such as aerospace, electrical, electronic etc. which provides greater flexibility in modelling of the irregular contours. CATIA V5 is the only solution capable addressing the complete product development process, from product concept specifications through product-in-service, in a fully integrated as associative manner. It facilitates the true collaborative engineering across the multi-disciplinary extended enterprise, including style from design, mechanical design and equipment and systems engineering, managing digital mock-up, machining, analysis and simulation



B] CRASH ANALYSIS:

The ANSYS Workbench platform is the framework unifying our industry-leading suite of advanced engineering simulation technology. An innovative project schematic makes it possible to build even complex multiphysics analyses with drag-and-drop simplicity. With bidirectional parametric CAD connectivity, powerful highly automated meshing, an automated project-level update mechanism, pervasive parameter management and integrated optimization tools, the ANSYS Workbench platform delivers unprecedented productivity, enabling process capture and Simulation-Driven Product Development.

C] ITERATIONS:

Bonnet iterations are carried out by changing geometry and by changing materials. For material iteration ,Aluminium and Steel is used.

D] EXPECTED RESULTS:

Iterations for geometry by changing dimensions and adding features like ribs will enhance the crashworthiness or not will be concluded by following parameters .Iteration for material affect the stiffness of the bonnet. More stiffness is required to absorb the energy. Bonnet should be designed in such a way that no impact energy should be transmitted o the occupants.

i) Shape deformation
ii)Von Mises stress
iii)Velocity
iv)Acceleration
v)Equivalent Strain

V.CONCLUSION

This paper helps us to understand the basic theory of crashworthiness and various standards in different countries for safety . Automobiles should be designed in such a way that they should be passes in above regulations.

ACKNOWLEDGEMENT

Thanks to Dr. G.V.Shah for his valuable contribution in developing the IJRSD article template.

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