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Validation of Toyota Camry for Frontal Impact and Studying The Effects of Bumper Reinforcements

[1] Abhilash S Rao, [2] Angu Sabariesh, [3] Anguraj, Chirag K
8th Semester BE
[1] [2] [3] PES Institute of Technology
Guides: Mr. Ganesh Kini, ESI Group India.
Prof. Rammohan B, Associate Professor, PES University

Abstract: **This paper "validation of toyota camry for frontal impact and study of bumper reinforcements" the simulation of vehicle crashes by using computer software has become an indispensable tool for shortening automobile development time and lowering costs. It also has huge impact on the crashworthiness of an automobile. This work reports on the simulated crash test of an automobile. The objective of this work is to simulate a frontal impact crash of an automobile and validate the results. The aim is also to alter some of the materials of the components with a view to reduce t he forces experienced during the crash. Computer models were used to test the crash characteristics of the vehicle in the crash. The model used here was that of a toyota camry 2012 model. The software used for the simulation is virtual performance solution. It is widely used by the automotive industry to analyze vehicle designs. It accurately predicts a car's behavior in a collision. The results obtained by the simulation were then validated by comparing it with the test results of the same test performed by the ncap (new car assessment program).**

***Keywords*: NCAP- New Car Assessment Program, VPS – Virtual Performance Solution, CMS – Crash Management System, MTOCO – Multiple Constraints, FMVSS – Federal Motor Vehicle Safety Standards**

I. INTRODUCTION

The world is moving towards faster mobility and establishing a strong network between cities. We must facilitate safer mobility as we quicken its pace. Hence, it is imperative to continually assess and improve the crashworthiness of a commuter vehicle. To do so with minimal cost and resources, we must look towards simulations. Finite Element Models can be closely analyzed and corrected, for either components that are being developed or even the ones that are experiencing field problems. The finite element method is comprised of three major phases: (1) pre-processing, in which the analyst develops a finite element mesh to divide the subject geometry into sub-domains for mathematical analysis, and applies material properties and boundary conditions, (2)solution, during which the program derives the governing matrix equations from the model and solves for the primary quantities, and (3) post-processing, in which the analyst checks the validity of the solution, examines the values of primary quantities (such as displacements and stresses), and derives and examines additional quantities (such as specialized stresses and error indicators).

CRASH – TEST

A crash-test is a form of destructive testing usually performed in order to ensure safe design standards in crashworthiness and crash compatibility for automobiles or related components. To test the cars safety performance under various conditions and during varied types of crashes, vehicle manufacturers crash test their cars from different angles, different sides and with different objects, including other vehicles. The most critical crash tests are the frontal impact and side impact tests. Our study would mainly concentrate on the full frontal impact of the vehicle with simulations for offset.

OUTLIN

The Automobile sector has been faced with many challenges to improve the crashworthiness of a vehicle. Many researchers are working on improving the occupant safety by increasing the energy absorption capability of a vehicle during a crash. The Frontal impact is the most common type of crash resulting in fatalities. In our project, we are working on improving the energy absorption of Toyota Camry during frontal impact by the addition of Aluminium Foam as reinforcement to the bumper. The modeling of foam and the explicit simulation of the crash test is done using the Virtual Performance Solution (VPS) package. The baseline test is conducted on a standard sled model with only the Bumper and Crash box of the car appended to the sled. Then, by carrying out the simulation and studying the results, the suitable geometry and type of foam is selected. This foam reinforcement is later added to the car model. The simulation is then carried out on this car model and compared with the standard full car model (without reinforcements). After the completion of this project, we would have proof to show that we can improve the crashworthiness of a vehicle using a suitable cost effective method of adding foam as reinforcement.

II. LITERATURE REVIEW

VALIDATION OF MATERIAL MODELS FOR CRASH TESTING OF CARBON FIBER COMPOSITES: PHYSICAL CRASH TESTING by Derek Board, Yijung Chen, Omar Faruque (Department of Passive Safety
Research & Advanced Engineering Ford Motor Company) Golam Newaz, Paul Begeman, Ali Seyed Yaghoubi. Yash Dixit (College of Engineering, Wayne State University)

This paper details the methodology and findings of the dynamic crash testing of both the steel and composite Front Bumper and Crush Can

(FBCC). Steel FBCCs were used to establish test protocols for six load cases. In addition, results obtained from steel FBCC tests were used to establish the crash performance targets required for designing a composite FBCC. Load cases used for the steel FBCCs were used to test the composite FBCCs so that the crash performance of these systems can be compared.

EFFECTS OF MANUFACTURING PROCESS IN CRASH SIMULATIONS by J Sasek, M Pasek, K Benes and V Glac. (ESI Group)

This article describes an impact of a manufacturing, which can significantly change real parts behavior. The influence of technology process is neglected in regular simulations. However, advanced finite elements solvers such as VPS make it possible to involve the manufacturing process in final simulations. It brings distortions and initial distribution of stress and strain into simulations.

UPDATED REVIEW OF POTENTIAL

TEST PROCEDURES FOR FMVSS NO. 208 by Office of Vehicle Research (WILLIAM T. HOLLOWELL HAMPTON C. GABLER SHELDON L. STUCKI STEPHEN SUMMERS JAMES R. HACKNEY, NPS)

The objective of a crash test for Federal Motor Vehicle Safety Standard (FMVSS) No. 208 is to measure how well a passenger vehicle would protect its occupants in the event of a serious
real world frontal crash. This is sometimes referred to as the crash-worthiness of a vehicle. This report reviews potential test procedures for evaluating frontal crash-worthiness.

III. METHODOLOGY

At first we start of by taking the all-round measurement of the CMS(bumper and crash box). The sled was modelled according to NCAP standards, after which the crash management system is appended to the sled using PLINK (welds). A rigid meshed wall is created. We then assign contacts and boundary conditions between the nodes of the sled and the crash management system. The system is given an initial velocity of 56kmph according to the testing standards and is submitted to the solver for simulation.

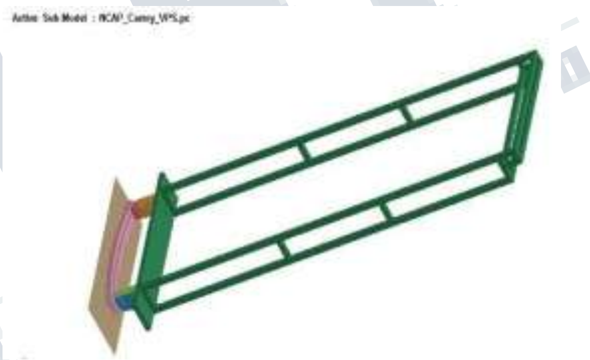

Fig: Sled model with CMS

A Full- frontal impact simulation is carried on a Toyota Camry 2012 model. The model is equivalent in weight to the actual car tested by the Global NCAP organisation. The Half-car model is chosen instead of the Full- car model in order to save the computational time. This is done in the following order:

1) The Full car model is Volume cut up to a suitable length behind the front wheels.
2) The CG node of the cut rear section is created and rigid connections are made from that CG node to the entire length of ends of front half using Multiple constraints (MTOCO).
3) The mass and Inertia properties of the cut rear section are added to that CG node.

In this way, similarity of the Half car model is maintained with the Full car model.

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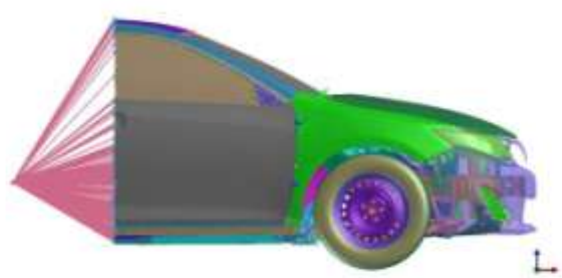

Fig; Half car model

This model is run using the same boundary conditions without and with Aluminium foam and results are compared. The foam is modelled and appended on the front portion of the bumper using a suitable adhesive such as Epoxy resin.

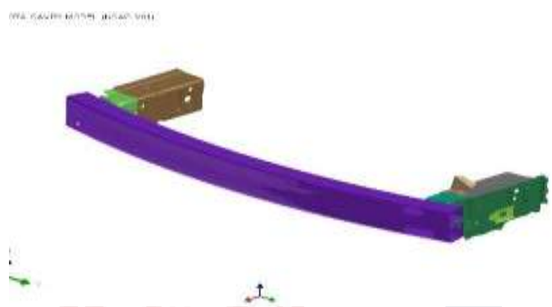

Fig: Crash Management System

Fig: Foam appendage in front of bumper

VI. BOUNDARY CONDITIONS

A rigid wall and rigid floor were meshed and constrained in all the 6 degrees of freedom. A non-penetrating contact was assigned between the car to floor and car to wall. The vehicle was given a linear velocity of 35 mph (56 km/hr) according to NCAP standards. The wheels were assigned the corresponding angular velocity. The car was also assigned with the gravitational acceleration. Other contacts such as PLINK, MTOCO and Rigids were assigned at suitable places.

V. MATERIAL SELECTION

The material was selected on the basis that it should be economical, light weight and the method of attachment to the bumper should be easy. Foam was selected as a suitable material agreeing with all the criteria. For the comparison, two kinds of foam- Aluminium foam and Polyurethane foam were chosen. After careful research on the pros and cons of the two materials, the following points were noted.

1) Polyurethane foam was found to be slightly cheap and lighter than Aluminium foam.

2) The major problem with the Polyurethane foam is that causes spring back effect after it has compressed. This would cause a jerk which is undesirable in the case of an impact.

Hence, Aluminium foam was chosen as a bumper reinforcement for the car and the properties of it are given below:

Young's Modulus	21 MPa
Density	435 kg/m3
Type	Closed Cell

The compression Stress- Strain curve of this foam was assigned to the material card of the VPS Solver.

Fig : Aluminium foam- Closed cell type.

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The material card for the foams in accordance to the solver is MAT 45 – Nonlinear strain rate foam.

VI. TIME STEP

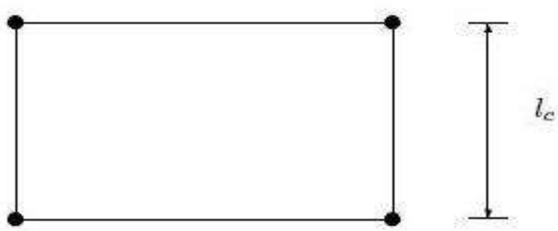
The time step is the incremental change in time for which the model is being solved. The time step should be kept small enough to account for all the minute changes in the analysis. Since, the mesh size is irregular in the structure a standard predetermined time step is inputted to the solver. The elements which have a time step lesser than the standard are added a non-physical mass such that the density increases without affecting other parameters, so that the dilatation wave speed gets artificially reduced thus, increasing the time step for that element. The standard time step inputted for the solver is 0.75 microseconds.

The Dilatation wave speed is calculated by using the formula,

$$c = \sqrt{E/\rho}$$

Minimum time step, $\Delta t = l/c$

Average element size of the model is 6- 8 mm.



For plate/ shell elements, the optimum time step chosen by the solver is 0.83 microseconds.

MASS SCALING

Mass scaling refers to a technique in which non-physical mass is added is added to the structure to achieve a larger explicit time step. However, adding mass to the structure leads to inaccurate results. In order to make the effect of mass scaling on the results negligible, it should be kept at less than 5%. Given below is the mass scaling info of both the shell and solid elements in the Half- car model:

SHELL ELEMENTS

No. of elements scaled	56237
Total mass before scaling (kg)	480.12
Total mass after scaling (kg)	484.61
Mass increase percentage (kg)	0.93

SOLID ELEMENTS

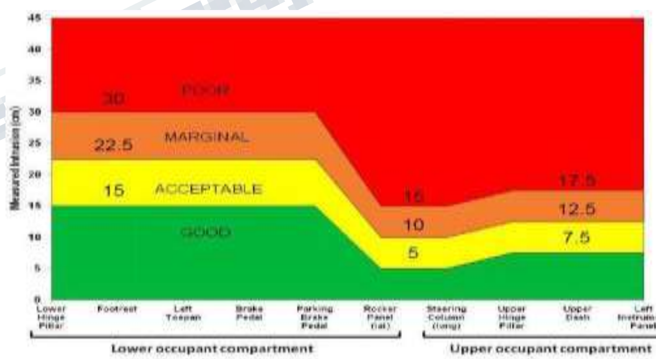
No. of elements scaled	12886
Total mass before scaling (kg)	229.9
Total mass after scaling (kg)	250.53
Mass increase percentage (kg)	8.97

Since, the number of solid elements in the model is negligible compared to shell elements, the effect won't be significant.

VIEWER

As accurate measurement and readings are quintessential for a frontal impact simulation to validate it with the NCAP test, time history can be extracted at predefined nodes. These nodes are positioned at the locations dictated by the NCAP. The salient points are:

- Engine Top,
- Engine Bottom,
- Firewall Left,
- Firewall Right,
- Left Brake Caliper,
- Right Brake Caliper



This chart defines the permissible levels of intrusion at each accelerometer location. As discussed earlier, the most effective way to minimize cabin intrusion is to support the structure along the load path during crash. Sectional views were used to compare the paths of deformation in both cases. The section view shown below has a difference of 15mm at the brake caliper. The orange section is corresponding to the reinforced bumper. The animation control tool was used to compare the simulation of the half car model to the NCAP test. Some of the key frames are

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illustrated below. The viewer has the ability to superposition a video format on to the crash simulation to compare with ease.

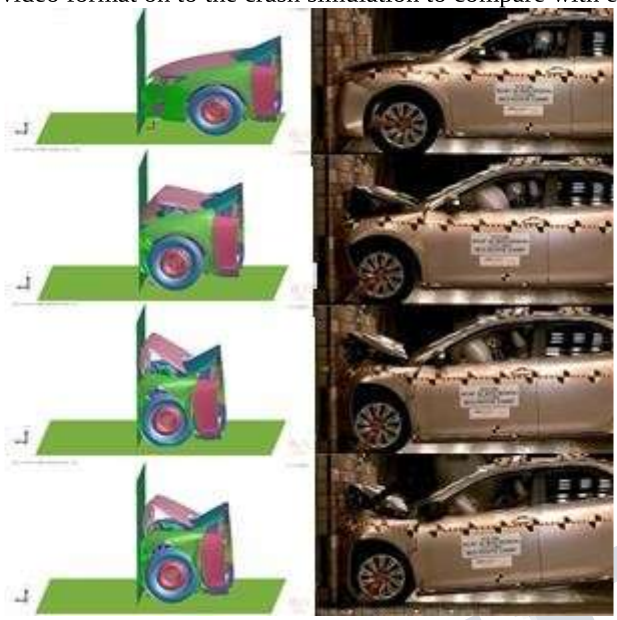

Fig: Frame to frame comparison of the actual test and the simulation.

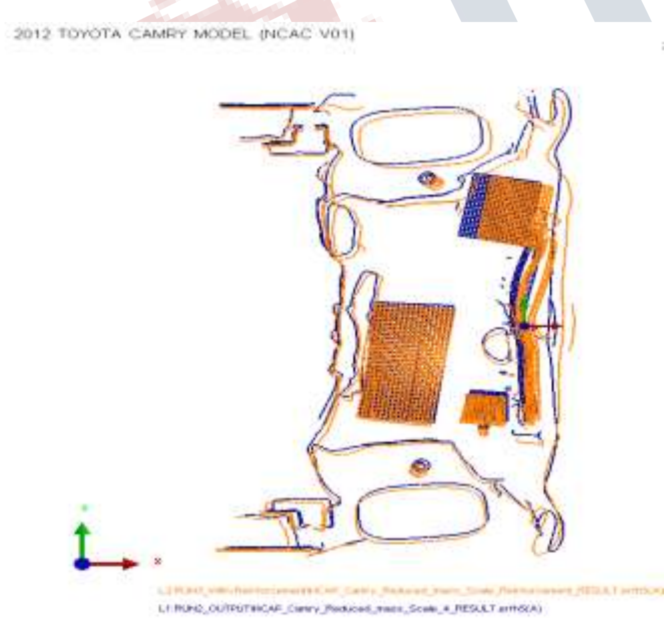

Fig: Section cut to study the difference in displacement after the reinforcement is added.

GRAPHS

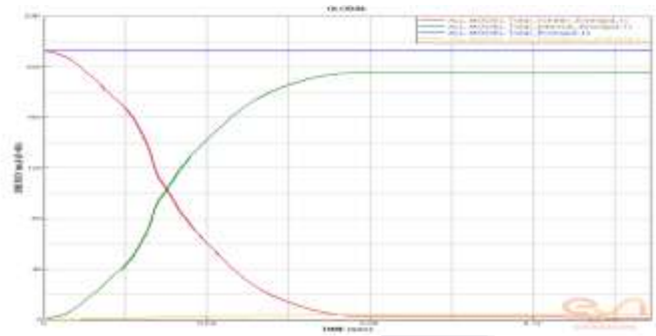

Fig: Energy curve

The energy graph for the reinforced model comprises of four plots,

- Total Energy (Blue Curve) – The total energy of the system is the sum of all the energies, such as internal energy, kinetic energy and hourglass energy. The total energy of the system is conserved, hence the plot is horizontal
- Kinetic Energy (Red Curve) – The model had an initial velocity of 56km/h and the wheels of the car were given angular velocity to match. There is a sharp drop in kinetic energy on impact.
- Internal Energy (Green Curve) – Nearly all the kinetic energy gets transformed into internal energy on impact, the shell elements undergo plastic deformation, in the process they amass strain energy which is stored in each body.
- Hourglass Energy (Yellow curve) – It is the amount of energy lost due to improper behaviour of certain light elements. It was found to be 6% of the total energy.

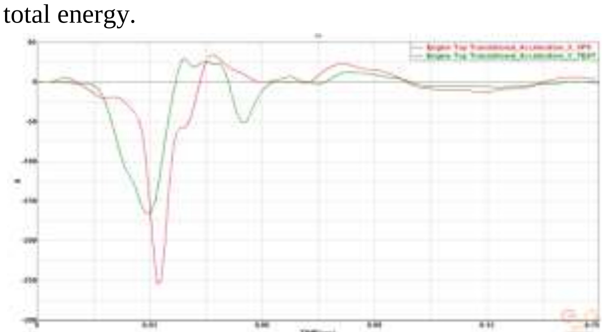

Fig (1): ENGINE TOP ACCELERATION (SIMULATION vs TEST)

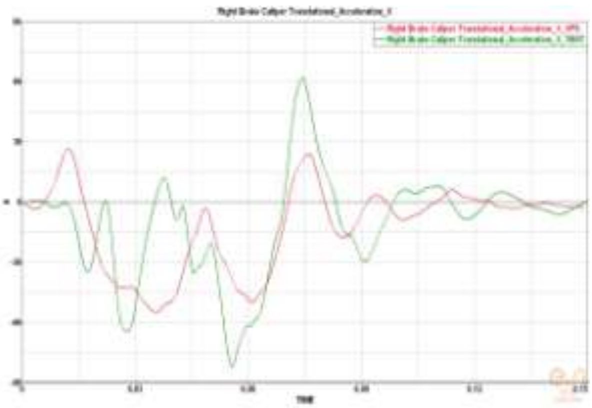

Fig (2) LEFT BRAKE CALIPER (VPS and TEST)

Fig (3) FLOOR REAR LEFT (VPS and TEST)

The graphs above show the comparison of transnational acceleration between the VPS simulation and the actual NCAP test. These plots help us validate the frontal impact simulation that was performed. The abrupt peaks seen in the graphs of the simulation are because of certain misbehaving elements and hence these abnormalities must be ignored.

VII.FURTHER SCOPE

We intend to continue our research on this project and optimise the Bumper reinforcements for better crashworthiness. The research will be carried out on the following things:

1) Appending Polyurethane foam to the bumper and compare the results with that of Aluminium foam so that the better material can be chosen.

2) Carrying out iterations on different kinds of geometry such as Honeycomb structure of both the foams.

3) Carry out tests on Frontal offset and Pole Impact and study the results.

4) Append the foam on any suitable hollow sections such as Crash box which would improve the crashworthiness thus, reducing cabin intrusion.

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