EXPLORATORY STUDY ON THE SUITABILITY OF AN AIRBAG FOR AN INDIAN MOTORCYCLE USING FINITE ELEMENT COMPUTER SIMULATIONS OF RIGID WALL BARRIER TESTS

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ABSTRACT

Airbag's feasibility for the large touring motorcycles in mitigating severe injuries or avoiding fatality to the rider in a fatal crash has been established. However, airbag's suitability is not yet established for the smaller motorcycles which are used in India and other South Asian Countries; as means of transport rather than amateur riding. The current study is a first of its kind to address an issue of safety of Indian motorcyclists in a fatal crash by airbag. Study was aimed at finding appropriate: triggering time of airbag inflation process, backing surface, location and orientation of airbag module, and size of the airbag; in restraining effectively and absorbing maximum kinetic energy of the rider in the primary fatal impact with the rigid wall barrier. The study undertaken was the great challenge in the developing country such as India where there is no facility to conduct an actual barrier test on a motorcycle with a dummy installed with all the instrumentations. It is also extremely difficult to get the data and design details of every object used in the actual crash tests conducted elsewhere in the world. As per ISO 13232 standards [(6)], rigid wall barrier test simulations of motorcycle with airbag and rider were performed to arrive onto any conclusions. A Finite Element (FE) model of a representative Indian motorcycle of 100cc was developed which behaved realistically in the barrier test simulation. The developed realistic models of folded airbag, MATD neck and helmet were used. MATD neck was integrated into the available ATD model. All the FE models of the components were integrated to have a complete system to conduct barrier test simulations in 90 degree and 45 degree angles of impact. Simulations were performed using nonlinear FE software Pamcrash^{TM}. It was found that the sensor time should be lowest possible for triggering airbag inflation process due to smaller space available with the motorcycle. A need of a backing surface was felt for properly restraining the rider by airbag. Different alternate arrangements were studied to find out proper location and orientation of the airbag module in the motorcycle. Effect of different sizes of airbag was studied in absorbing the kinetic energy of the rider during the crash. The study found out appropriate triggering time, backing surface, location and orientation of airbag module and airbag size in effectively restraining and absorbing maximum kinetic energy of the rider in the fatal crash. The scope of the study was the primary impact, where the rider's head impacts into the rigid wall barrier in the fatal crash. The study has not considered following: a scenario of fall of a rider on the ground, angular impact sensitivity analysis, presence of a pillion rider, and full scale crash tests mentioned in ISO 13232 standards. At the end of this study it can be said that the broader research question of suitability of the airbag in Indian motorcycle in mitigating injuries to the rider in the fatal crash is answered in affirmative.

INTRODUCTION

Airbag's feasibility for the large touring motorcycles in mitigating severe injuries or avoiding fatality to the rider in a fatal crash has been established. It has taken more than three decades of research to establish the feasibility of airbags at least for large touring motorcycles [(7)]. This is due to the complexities involved in motorcycle airbag research. However, airbag's suitability is not yet established for the smaller motorcycles which are used in India and other South Asian Countries; as means of transport rather than amateur riding. This could be because the issues of airbags for smaller motorcycle (~100cc) are of concern only to developing countries like India. In India, the vulnerable road users such as pedestrians, bicyclists and two wheeler riders account for 60-80% fatalities. The registered motorized two-wheelers, including motorcycles, mopeds and scooters, account for 70% of total vehicle population. The fatalities of motorized two wheelers in road accidents account for 20-30%, making it second largest after pedestrian fatalities 40-50% [(1)]. As reported [(5)], a typical scenario of a motorcycle crash is a frontal impact (65.2%) of a motorcycle with an opposing vehicle (45.8%) where the rider separates from the motorcycle and hits the opposing vehicle (45.8%) or ground (37.4%) resulting in fatality due to the severe injuries to upper body parts (84.4%). The rider's injury regions are head 48.6%, neck 9.1%, chest 18.3%, abdomen 8.4%, whole body 8.4% and other part 7.2%. Thus, to arrive on beneficial or harmful effect of an airbag into the motorcycle, it is important to monitor the kinetic energy of the rider's head during impact.

The study undertaken was the great challenge in the developing country such as India where there is no facility to conduct an actual barrier test on a motorcycle with a dummy installed with all the instrumentations. It is also extremely difficult to get the data and design details of every object used in the actual crash tests conducted elsewhere in the world. With these limitations, safety of motorcyclist was studied using Finite Element (FE) Analysis, and FE models of the objects under consideration were developed by reverse engineering technique wherever possible. The study has not considered following: a scenario of fall of a rider on the ground, angular impact sensitivity analysis, presence of a pillion rider, and full scale crash tests mentioned in ISO 13232 standards. The broad research question addressed in present work is that whether the airbag system is suitable for Indian motorcycles in mitigating severe injuries to its riders in the event of a fatal crash. The current exploratory study is a first of its kind to address an issue of safety of Indian motorcyclists in a fatal crash by

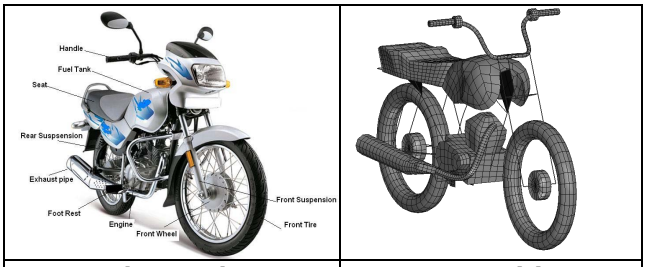
airbag with detailed Finite Element Analysis. The study was aimed at finding appropriate: triggering time of airbag inflation process, backing surface, location and orientation of airbag module, and size of the airbag; in restraining effectively and absorbing maximum kinetic energy of the rider in the primary fatal impact with the rigid wall barrier.

MODEL DEVELOPMENT

The essential components of the motorcycle airbag research are a motorcycle, its rider, helmet and airbag. In order to investigate the suitability of airbags in Indian motorcycles using computer simulations, it is required to develop a motorcycle model of most representative motorcycle in India, develop a dummy model which can duplicate the rider behaviour, and develop an accurate helmet model. Also, to assess the rider interaction with the deploying airbag in realistic way, a neck model should be more biofidelic. According to ISO 13232 standards, Motorcycle Anthropometric Test Device (MATD) is meant to duplicate the rider in crash environment. The newly designed neck known as MATD neck is specially designed to handle airbag interaction.

Motorcycle Model

A typical motorcycle of 100cc engine capacity is taken as the representative Indian motorcycle. The motorcycle under study was selected and dimensional details of its individual parts were obtained. Considerable time was spent for this exercise with the available tools such as the vernier caliper, spirit level, rule, weight balance, camera etc. The weights of the parts were measured either using the spring balance or weighing machine depending on their weight. Some of the parts were hung on the hook and their period of oscillation was measured to know their moment of inertia and location of the center of gravity. To measure dimensions of the complex shapes, the arrangement of spirit level and scales was made in such a way that the unit became a small Co-ordinate Measuring Machine (CMM). The models of the individual parts were then developed using HYPERMESH™ software for the measured dimensions. The photographs were utilized to clarify the construction details of the motorcycle. There were some parts which were meant for the decoration purpose or were not contributing towards strength of the motorcycle during crash. Their dimensions were measured but their models were not made. During the measurements of the individual parts, at most care was taken of the attachment points. The individual parts were assembled by using the information of these attachment points. The models of the individual parts were assembled with each other by appropriately choosing the joints, nodal constraints or simply by the 'node merge' option. The subassemblies of the front tire, rear tire, front suspension, rear suspension, and the handle were assembled appropriately at the attachment points. Thus, the assembly of the individual parts and these subassemblies made the complete motorcycle unit. The following *Figure1* shows a photograph and FE model of the motorcycle.



Photograph	FE model

Figure 1 Indian Motorcycle

Motorcycle Barrier Test Any motorcycle model whether it is the Finite Element or Rigid Body is generally validated in a rigid wall barrier test. The purpose of the rigid wall barrier test is to make sure that the motorcycle model developed acts as a unit and produce reasonable wall forces by following proper dynamics. Also, in a barrier test, the motorcycle components' integrity is getting checked. Once it is ensured that the motorcycle act as a unit then it can be further subjected to Full-Scale-Tests where the dummy will be installed and it would be impacting into other opposing vehicle. The ISO 13232 standards specify the barrier force as one of the variables to be measured in a motorcycle dynamic testing. Thus, a barrier test of the motorcycle is must to evaluate the performance of any intended safety device into the motorcycle.

In present study, a FE model of a motorcycle was developed and validated by correlating its barrier test simulation results with the actual barrier test conducted by Mukherjee et al. [2002] [(8)]. As per ISO 13232 standards, the motorcycle model was simulated to impact into a rigid wall. The properties of the individual parts of the motorcycle were taken from authentic sources and input to corresponding models. The snapshots of the barrier test simulation are shown in Figure 2.

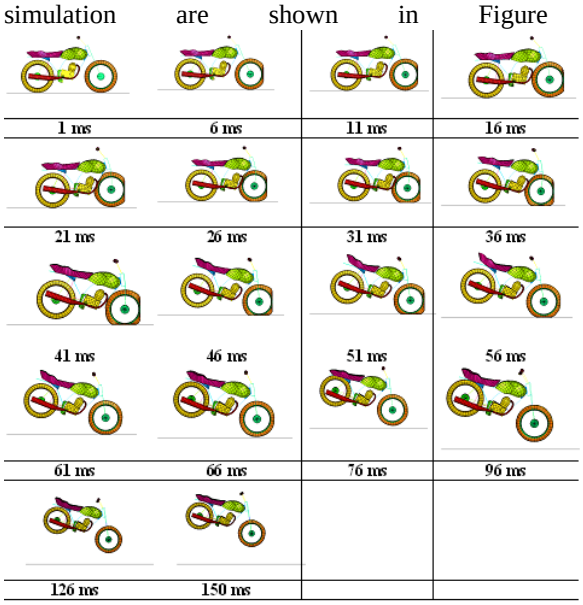
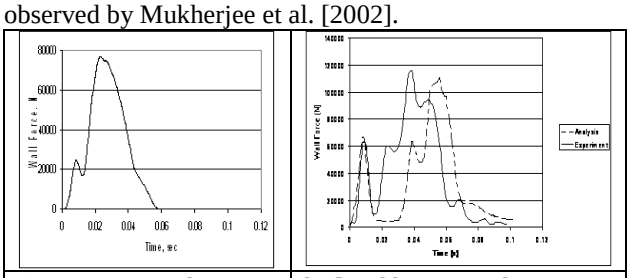


Figure 2 Simulation states for Motorcycle in Barrier Test

The results of the simulation were compared with Mukherjee et al. [2002]. It was observed that the wall forces curve of the barrier test simulation followed similar signature of the experimental curve of Mukherjee et al. [2002]. Figure 3 shows the comparison of the simulation results with the experimental and simulation curves observed by Mukherjee et al. [2002].



a) Present Simulation	b) [Mukherjee et al., 2002

Figure 3 Wall Forces comparison with [Mukherjee et al., 2002]

The magnitude of the wall forces was found to be proportionate to the motorcycles weights i.e. 100kg in present study and 218kg by Mukherjee et al. [2002]. It was concluded that the motorcycle model of present study could be used for further tests simulations.

Motorcycle Anthropometric Test Device (MATD) Neck

Depending on the crash scenario an unconstrained rider of a motorcycle can follow innumerable trajectories. The crash dummy mostly used in the automobile crashes is 50 percentile male Hybrid III dummy which was meant for frontal crashes. As per ISO 13232 standards, certain modifications are done in 50 percentile Hybrid III dummy to make it MATD. The MATD neck is specially designed to accommodate various postures of the rider and mimic the multi-directional impact scenarios. This is essential to arrive at any conclusion with reasonable accuracy on injury prediction for the motorcyclist. ISO13232 has given the construction details as well as performance criteria for the MATD neck. Figure 4 shows photographs of the actual MATD neck available to model MATD neck.

Front View	Side View

Figure 4 Photographs of MATD neck [2]

The MATD neck model should satisfy each and every corridor specified in ISO13232 for studying interaction with the deploying airbag in realistic sense. The tests specified in ISO13232 are the Frontal Flexion, Extension, Lateral Flexion and Torsion. For every test there are certain corridors of the angle and position of the neck to be satisfied. Dimensions of the each component of the MATD neck was estimated from the photographs. The MATD neck model was developed following the construction details specified in ISO 13232 standards and using estimated dimensions. The material properties were input to MATD neck model from authentic sources for simulating dynamic tests mentioned in ISO 13232 standards. The dimensions of the MATD neck were finalized by iterating on material properties of the mid-section rubber disks in dynamic tests simulations. Figure 5 shows MATD neck model.

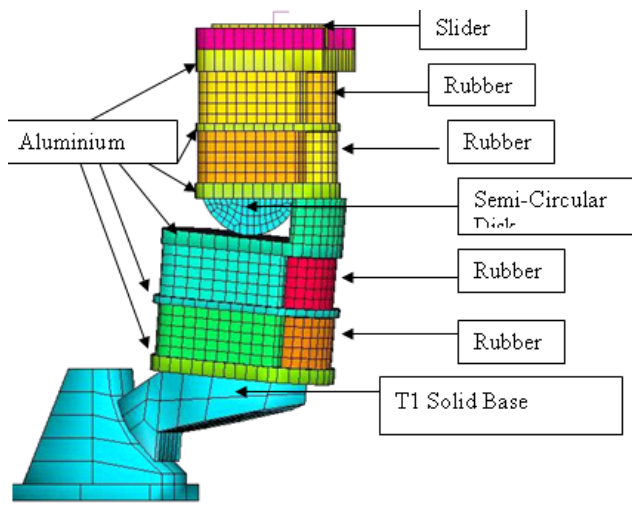


Figure 5 MATD Neck Model

The MATD neck model satisfied all the dynamic tests corridors of Frontal Flexion, Extension, Lateral Flexion and Torsion tests mentioned in ISO 13232 standards shown in appendix [2].

Helmet

As shown in Figure 6, the FE mesh of the helmet model was available. The task at hand was to validate the model against the available experimental results for accommodating it in the crash simulations of the motorcycle.

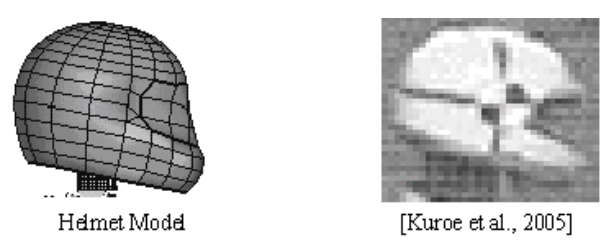


Figure 6 FE Model of the Helmet and Photograph of the actual helmet used by Kuroe et al. [2005][7]

Helmet Drop Tests Helmets are impacted in drop tests to check their performance in a crash event or in a single fall scenario of the motorcycle rider. The helmet model and the actual helmet used by Kuroe et al. [2005] [7] looks similar in size and shape. The impact tests simulation results were compared with the experimental results reported by Kuroe et al. [2005] for different impact velocities of the helmet. It is reported that four impacting speeds of 5.94 m/s, 6.26 m/s, 7 m/s and 8 m/s. were used to test the actual helmet. It was reported that the actual test helmet was designed for maximum of 10m/s impact speed. So beyond this speed it would fail. Table 1 shows results of the helmet drop test simulations with the finalized inner foam properties as mentioned earlier. As shown in Table 1, the results of the helmet drop tests conducted by Kuroe et al. [2005] were reported in terms of the Head Injury Criteria (HIC) values. Last row of Table 1 shows that the helmet model was simulated for a higher impact speed of 13.4 m/s. In this case, the head form did touch the helmet outer shell. The helmet outer shell was in contact with the rigid plate which led to a higher acceleration peak and HIC value of the Head CG.

Table 1
Results of Helmet Impact tests simulations

Impacting Velocity in m/s	Head form Center of Gravity (CG) Acceleration in G	Head Injury Criteria (HIC)	Head Injury Criteria (HIC), Kuroe et al., 2005
5.94	223.4	1436	1391
6.26	272.1	1888.4	1653
7	300.75	2562.8	2500
8	350.1	4584	4254
13.4	12587.4	2.37E+06	NA

Figure 7 is plotted from the results of Table 1. Figure 7 shows a close match between the simulation results of the helmet model under the study and the experimental results of Kuroe et al. [2005] with different impacting speeds in the helmet drop tests.

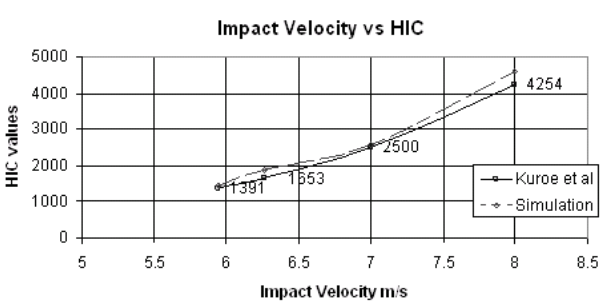


Figure 7 Comparisons of helmet impact simulations with [Kuroe et al., 2005]

The Finite Element helmet model thus can be said to be experimentally validated not only for the single impact speed but for four different impacting speeds. It may be noted that the helmet model would produce the HIC values as mentioned by Kuroe et al. [2005] for the impacting speeds lying in between the tested impacting speeds. Thus, in a crash simulation the helmet model would resemble the actual helmet used by Kuroe et al. [2005]. Moreover, the close match is for HIC values and not only for the head CG acceleration.

Airbag

The airbag as a passive safety device fitted in the automobiles is fast gaining public acceptance. The concept of the airbag in motorcycles is new compared to airbags for four wheeled vehicles. In this regard, currently passenger side airbags, which have a larger volume than the driver side airbags, are considered into the motorcycles.

Modeling of Folding of Airbag Mesh The rider's position varies with the motor cycle model and rider's style, and causes the rider to be often out-of-position i.e. rider comes in the trajectory zone of the inflating airbag. This is a dangerous situation as the airbag inflates within 40 ms and the speed of the airbag material coming out of the airbag module is around 200 mph (321 km/hr) [3, 9]. For this type of situation, the folding of the airbag is important which greatly influences the interaction between the rider and inflating airbag. Thus, to assess injuries of the rider reasonably in the simulations of the motorcycle crash, it is important to model the folded airbag in a realistic way. However, the modeling of the folding of the passenger side airbag is a time consuming and a tedious job. The commercial software tools used for modeling of the folding of the passenger side airbag do not give a realistic inflation process due to large distortion of airbag mesh elements and penetration problems.

In this work, new innovative method [3] is developed to model the folding of passenger side airbag mesh. Series of simulations were carried out for getting the folded passenger side airbag mesh. Initially, the undeformed mesh containing six layers of cloth was generated in the Finite Element software IDEAS™. For further folding simulations, the mesh was exported to PAM-CRASH™. The fold sequence was modeled using the simulations so as to duplicate the manual folding process in PAM-CRASH™. For each simulation of folding, the mesh was held between the rigid planes and these planes were given certain velocities corresponding to the folding process which gave folded airbag mesh of the complex shapes. The sequence of folding was similar to the manual folding of the airbag. Instead of hands, the rigid planes were used for the modeling of the folding on the passenger side airbag mesh. Figure 8 shows initial un-deformed mesh ready for series of folding simulations by rigid planes.

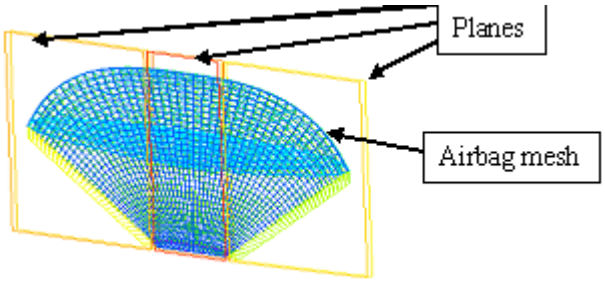


Figure 8 Initial Mesh and Rigid Planes

Annealing The appropriate state of *.DSY file from the previous simulation of the fold was selected. This file was opened in GENERIS™ and exported as mesh file *.unv. This *.unv file was again opened in GENERIS™ and saved as *.pc file by giving certain definitions. In this *.pc file the planes were defined as fixed rigid bodies and the airbag mesh was allowed to move inside the fixed planes. Thus, during the simulation, the contact forces between the airbag mesh, generated in the previous folding simulation, got reduced as it was allowed to relax inside the rigid planes. This simulation is called as annealing as it resembles the real annealing process in metallurgy. This simulation of the annealing was carried out after each simulation of the folding for reducing the contact forces between the airbag materials. Figure 9 shows a simulation state after several folding and squeezing of the airbag mesh.

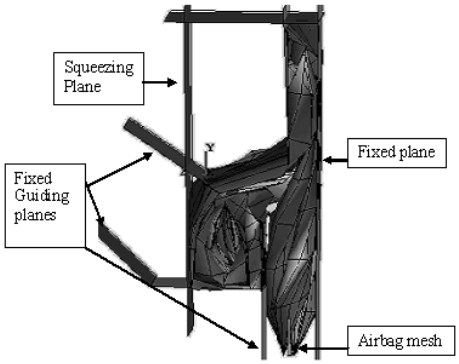


Figure 9 Arrangements of planes guiding the airbag mesh

Figure 10 shows the final state of the folded airbag mesh and surrounding rigid planes.

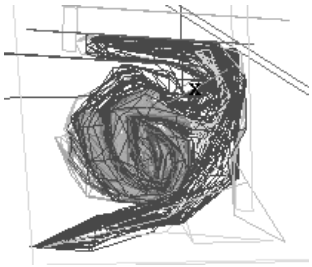


Figure 10 Side View of the final state of the folded airbag mesh

The properties related to airbag inflation process were taken from authentic sources. The inflation process of the folded airbag mesh was found to be in a better agreement with the inflation process of the unfolded airbag mesh. Figure 11 shows inflated folded airbag mesh.

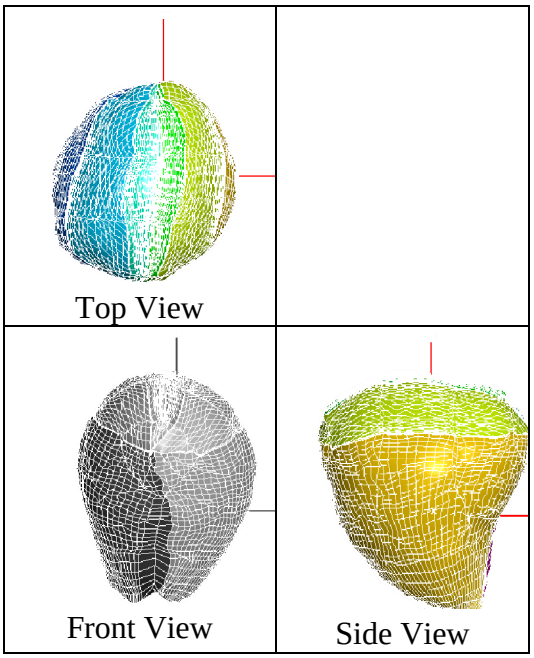


Figure 11 Inflated folded airbag mesh

Figure 12 shows simulation states of airbag inflation process. Airbag inflates within 40-50 ms as reported [5, 9].

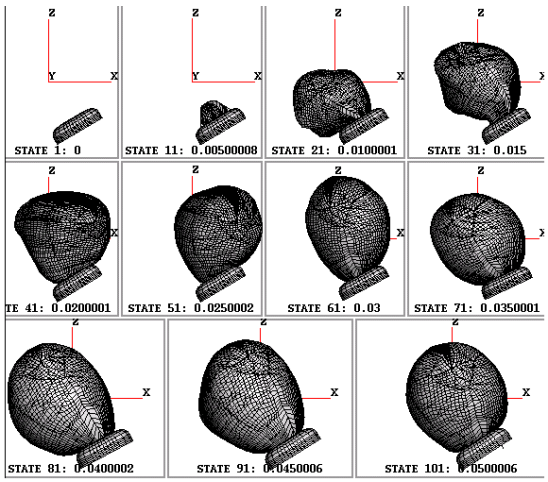


Figure 12 Simulation States of the inflation of the airbag

The operating pressure i.e. airbag internal pressure at which the occupant is intended to impact onto the airbag should be 50-60kPa as observed by Yamazaki et al. [2001] [9]. A very high internal operating pressure will lead to rebound of the occupant, whereas a small pressure will render the airbag ineffective in restraining the rider. The airbag mass flow and size of the airbag mesh was scaled appropriately to get the desired operating pressure 60kPa for each size of the airbag used. Figure 13 shows comparison of the internal pressure of the airbag with Yamazaki et al [2001].

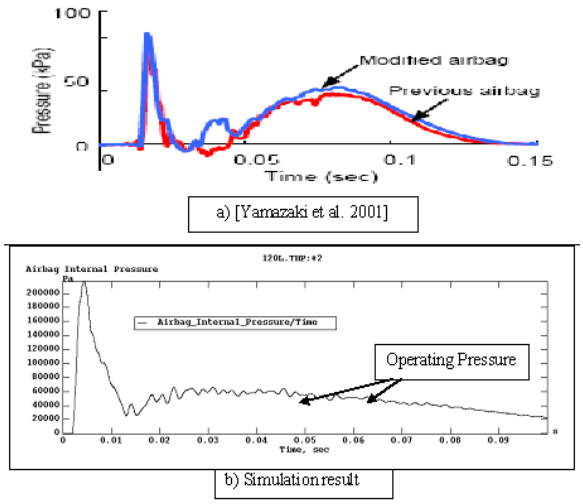


Figure 13 Airbag Internal Pressure curve compared with [Yamazaki et al., 2001]

The initial peak value of internal pressure of the airbag depends on the folding pattern of the airbag. The folding pattern of the airbag differs in both cases so the initial peak value differs as shown in Figure 13. Thus, it was concluded that the folded airbag mesh gave realistic inflation and could be used for further simulations for the motorcycle.

<u>Airbag Mesh Sticking Phenomenon</u> Generally, the airbag is stowed inside the airbag module i.e. casing. When gas starts filling the airbag, it's inside pressure increases sufficiently high to break open casing cover. Thus, the airbag fabric gets ejected out of its casing with high velocity. The inflation period of airbag was around 40 milliseconds (ms). The velocity at which airbag fabric gets ejected was reported between 200 to 300mph i.e. 320 to 480 kmph [(5)]. In reality it is observed that the airbag fabrics do not stick to casing of 8 to 20mm thickness during inflation. However in FE modeling, it was observed that airbag nodes got stuck with the casing (8.5mm thick) shell elements during the inflation as shown in Figure 14. This phenomenon of airbag elements getting trapped into the casing elements is termed as sticking. Due to this sticking phenomenon, the airbag could not be deployed as required to effectively absorb the kinetic energy of the passenger. The sticking phenomenon restricts smooth inflation of the airbag out of its casing.

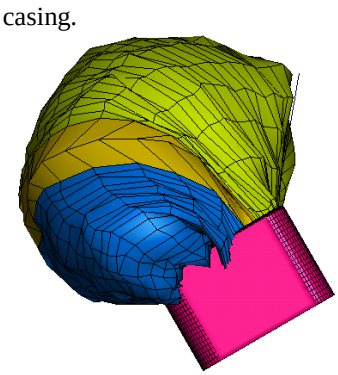


Figure 14 Airbag Penetrations with Casing

The following approaches were applied to avoid the sticking phenomenon between the airbag and its casing: i) Refinement of casing mesh and ii) Making casing with solid elements. Due to high velocity of the airbag nodes and size of airbag elements, the contact algorithm did not work with the refined mesh of the casing. Also, it was observed that the size of the airbag elements were more compared to the casing thickness. Thus, the refinement of the casing mesh did not solve the sticking phenomenon. It was thought that the solid elements of the casing may avoid penetration of the airbag mesh. The casing with larger thickness of 20mm was made with the hexahedron solid elements. The airbag elements of the bigger size easily crossed the casing thickness and remained there. Thus, there was no use of making the casing with solid elements to avoid sticking phenomenon of the airbag into its casing.

Last approach iii) Increasing thickness of casing was tried. It was observed that the airbag element length was bigger than casing thickness which caused nodes of the airbag element crossing over the casing elements and staying there. Thus to avoid penetration of the airbag nodes, the casing thickness was gradually increased. Figure 15 shows casings of various thicknesses. In all the cases, the height of the casing was kept same. Thickness of casing was increased by scaling the casing mesh in X-Y horizontal directions appropriately. It was observed that for 15mm to 50mm thickness of the casing, the sticking phenomenon gradually reduced but could not be avoided for a few elements particularly at the top edges of the airbag module.

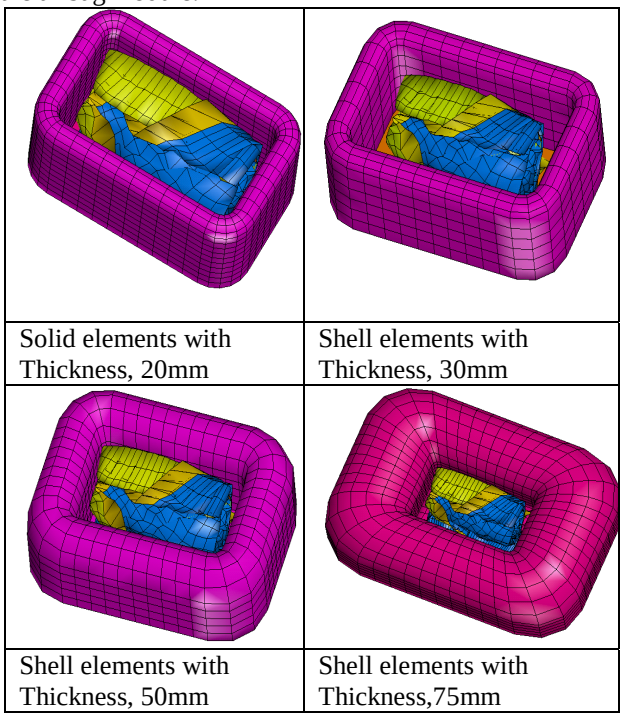


Figure 15 Casing with varying thickness

As shown in Figure 16 it was observed that the penetration of the airbag nodes inside the casing elements was completely avoided when the casing thickness was

75mm. Thus, the airbag came out of the casing smoothly during inflation simulation.

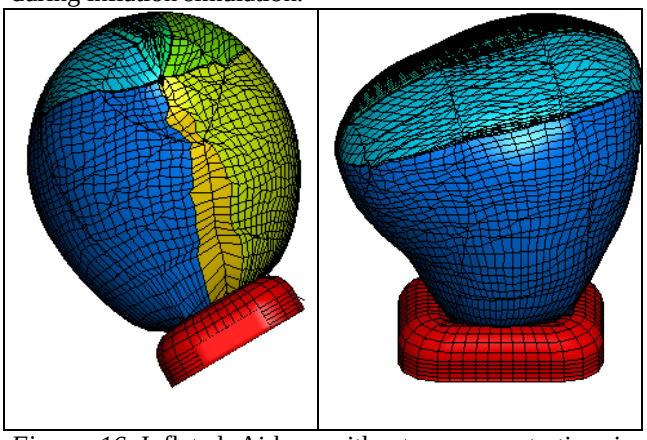


Figure 16 Inflated Airbag without any penetration in casing width 75mm

Although, in reality casing thickness is 8-20 mm but for simulation purpose it was taken as 75mm.

Selection of Airbag Sizes It was found that driver side airbags which are smaller in volume were too small to restrain a motorcycle rider by the airbag during a crash event. Therefore, larger volume airbags called as passenger side airbags were tried to restrain the motorcycle rider properly. Earlier, 65L driver side and passenger side 70L, 90L, 100L, 110L, 120L, 130L, 142L, 152L etc airbags were tried by the researchers for motorcycles. The choice of selecting a particular size of airbag for their motorcycle model was seemed to be dependent on their engineering judgment. In present case, the airbag sizes were selected based on the information available in literature. Finnis [1990] [(4)] found that 90L and 100L sizes airbags for 125cc motorcycle model were ineffective. Therefore higher size airbag of 110L is taken for the current study as a lower bench mark. Yamzaki et al [2001] [(9)] rectified the problem of increased injury level of rider with 140L size airbag from earlier 120L size airbag for their 1500cc motorcycle model [(9)]. Therefore, 142L size airbag size is selected in this study in anticipation that it may give similar results as reported by Yamazaki et al [2001]. Further, Kuroe et al [2005] used 157L airbag for their 1800cc motorcycle. Therefore, 153L size airbag is considered in present study to verify effect of a larger size airbag on restraining the rider in a few cases. It may be noted that it is difficult to get an exact size of the airbag as required by scaling the mesh and airbag parameters because of stretching of the airbag fabric elements.

Finally, the airbags chosen in present study are categorized as 110L small airbag, 142L midsize airbag and 153L as large airbag.

Triggering Time for Airbag Inflation The triggering time of airbag inflation is crucial to evaluate an overall performance of the airbag in a crash event. An ideal scenario of a dummy getting impacted into an airbag after it gets fully inflated could not be achieved in the initial configuration (described in next sections) of the airbag because of the constraints such as the early dummy movements and the space available for the airbag inflation.

As reported by Iijima et al. [1998], the accelerometers were used as sensors to detect the crash event and accordingly trigger the airbag inflation mechanism. The firing time calculation method was mentioned as follows : If sensed acceleration (rearward/downward) exceeds 9g (g=9.81 m/s^2) start “velocity change” calculation; if “velocity change” exceeds 2.4 m/s, send trigger signal; if “velocity change” does not exceed 2.4 m/s and acceleration becomes less than 9g, stop “velocity change” calculation, and reset to zero. It was observed that the sensor system took 10 to 12 ms time to calculate velocity change exceeding 5.7 m/s value in the crash configurations as mentioned in ISO 13232 standards, where a motorcycle with 30 mph i.e. 13.4 m/s velocity impacted into a Corolla passenger car. Similarly, it took 15 to 21 ms time to calculate the velocity change in crash events where a motorcycle with 20 mph impacted into a Corolla passenger car. Thus, a typical time to make judgment about the crash event is in the range of 10 to 21 ms.

In the present study it was assumed that similar sensor system was installed to detect the crash event. According to ISO 13232 standards, in the rigid wall barrier tests, 13.4 m/s i.e. 30 mph impacting velocity of the motorcycle is considered. For 13.4 m/s impacting velocity, the judgment time mentioned is 10 to 12ms. However, in this study the rigid wall barrier was considered instead of passenger car so the judgment time was further reduced to 9ms. Thus, the minimum possible delay time to trigger the airbag inflation was considered.

BARRIER TESTS

In barrier tests, the rigid wall or flexible wall can be moving or fixed. According to ISO13232 standards, in the barrier test with the fixed rigid wall, the impacting velocity of the motorcycle is fixed to 13.4 m/s i.e. 48.24 kmph. The barrier tests are primary requirements of the motorcycle airbag research. The motorcycle components are tested in a barrier test for their integrity. The motorcycle is subjected to a barrier test with a dummy installed onto the motorcycle with all the instrumentations. Further, it can be subjected to duplicate an actual crash event in which it gets impacted into the opposing vehicle. This test is known as Full Scale crash Test (FST) which is out of scope of this study. A motorcycle is pulled by the guided trolley release system and after getting required velocity of the impact just before the rigid wall or the opposing vehicle it can be released. This arrangement makes sure that the motorcycle does not have constraint before and after the impact as observed in an actual crash event. The dummy installed on to the motorcycle for these studies is kept at the desired position by the arrangement of the supports so that just before the impact, the dummy’s movement becomes unconstrained. The instruments are placed at the appropriate places to measure the crash variables in a

barrier test and FST. The details of the crash test procedures are given in ISO 13232 [2005] standards. The scope of this thesis is restricted to the fixed rigid wall barrier tests only. The essential components of the barrier tests are a motorcycle with/without safety device installed, rider with helmet and rigid wall.

All the models of individual components of the motorcycle airbag system were assembled in the Pam-Generis™ platform and the airbag inflation simulations were carried out in the Pam-Safe™. A uniform strategy was applied to assemble various models from different *.pc files. In *.pc file of a base component another model file was merged. Then, the appropriate transformations were applied to the model so that the model gets placed at the desired location. The file of these transformation was saved with another name *.pc. In this file, another model file was merged. Then again appropriate transformations were applied to newly merged model so that it gets placed at the desired location. This sequence was continued for positioning the models with respect to each other appropriately. The barrier tests simulations of the assembled models were run with the appropriate contact definitions, initial and boundary conditions.

The MATD neck was properly positioned into available ATD model. Helmet was positioned onto MATD head. Airbag was installed into the motorcycle. Overall performance of the airbag installed was studied in the rigid wall barrier tests simulations. There were two objectives defined for this study, first one to evaluate the performance of the airbag at the back drop that there is no backing surface to support the reaction forces of the airbag when the rider impacts into the airbag. Second, if there is any need of such backing surface then to find the alternate arrangement within a domain or provide the backing surface in terms of a windshield by appropriately designing it.

Base Simulation

The base simulations without the airbag inflation process were run. In first case, the angle of impact was 90^0 and in second case the angle of impact was 45^0. The results of these simulations were plotted by assigning the Node number 8001 for the Head CG, 8004 for the Chest center and 8007 for the Pelvis CG. All the airbag simulations of the rigid wall were compared with these base simulations. Figure 17 shows the snapshots of various simulation states where the motorcycle hits the rigid wall barrier at right angle i.e. at 90^0.

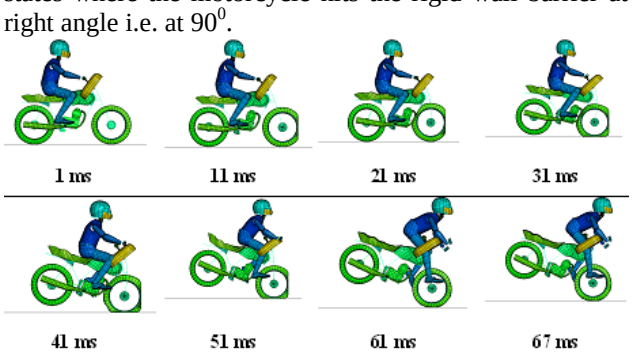


Figure 17 Motorcycle with 90^0 impacts- Base simulation

It can be seen from Figure 17 that after 21ms the dummy's legs got off the foot rest and the pelvis moved forward. At 31ms the motorcycle started to have pitching motion. Its rear tire started loosing the contact with the road. After 31 ms the hand got off the handle and it came out fully at 41ms as shown. After 41ms the pelvis came into contact with the fuel tank. That resulted in the dummy gaining some height and moving forward. At 51ms it shows that the dummy left the motorcycle. There was no contact defined between the legs and the airbag casing in this base simulation. In the base simulation there was no role of the airbag inflation. Moreover, there was no contact defined between the airbag casing and the dummy parts in any simulations. This is because the casing width was 75mm which was more than the realistic one. The casing width was kept more just to avoid the airbag inflation problems with the casing. After 51ms, the dummy's legs got straight and the head started moving towards the wall. At 61ms it shows that the pelvis gained certain height making the legs straight due to the gravitational field. Also, the motorcycle started moving backward from the wall and moving upward from the road. However, the dummy kept on moving in a forward direction. After 67ms its helmet first hit the rigid wall.

Figure 18 shows a velocity profile of the dummy's various parts such as the Head CG, Chest Center and Pelvis CG. The head velocity increased before its impact into the rigid wall due to momentum transfer phenomenon. This phenomenon can be explained using three rigid links connected with each other by revolute joints. Let us take the pelvis as a bottom link, chest as a middle link and neck as a top link. When we try to stop moving links at the bottom most end of the pelvis, then due to momentum transfer the chest link imparts linear as well as rotational motion to the neck link. Then the neck link transfers additional kinetic energy from its bottom end to its other end at the top. Thus, although all links are moving with certain velocity but due to stoppage of the bottom most links at its bottom end; greater velocity is imparted to the loose end of the neck link where the head gets placed.

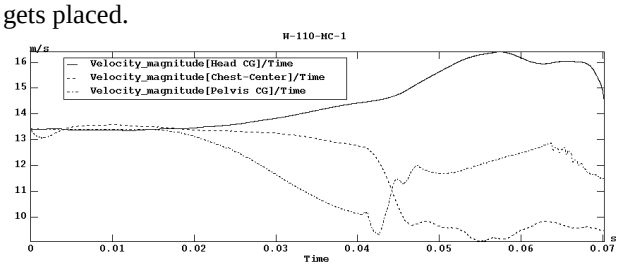


Figure 18 Motorcycle with 90^0 impacts - Velocity profile of MATD parts

Figure 19 shows the snapshots of the simulation states for 45 degree angle of impact. For more clarity, the snapshots are placed such that the first row shows the front view and second row (below the first row) shows its top view at every time step of 10ms. In the front view one can not get clear idea about the crash event. It is seen from Figure 19 that although the motorcycle handle got titled due to impact of the rigid wall, the dummy head continues to move forward towards the rigid wall due to its inertia. It is seen from Figure 19 that the hands got off the handle at

20ms. At 30ms the motorcycle got titled along with the 45^0 inclined rigid wall. As shown in Figure 19, the right leg of the dummy got lifted during 40 to 50ms period. The seat and the fuel tank offered resistance to the right leg and the pelvis after 40ms. Due to this the pelvis velocity got reduced suddenly as shown in Figure 20. But due to sliding of the motorcycle along the rigid wall, the resistance from the fuel tank and seat to the pelvis got released. This resulted in spike in the velocity curve of the pelvis which continued to move forward steadily after 50ms. The chest continues to move forward with a reduced velocity due to reduction in velocity of the pelvis. However, the head continued to move forward with a slightly increased velocity. At around 80ms it got impacted into the rigid wall.

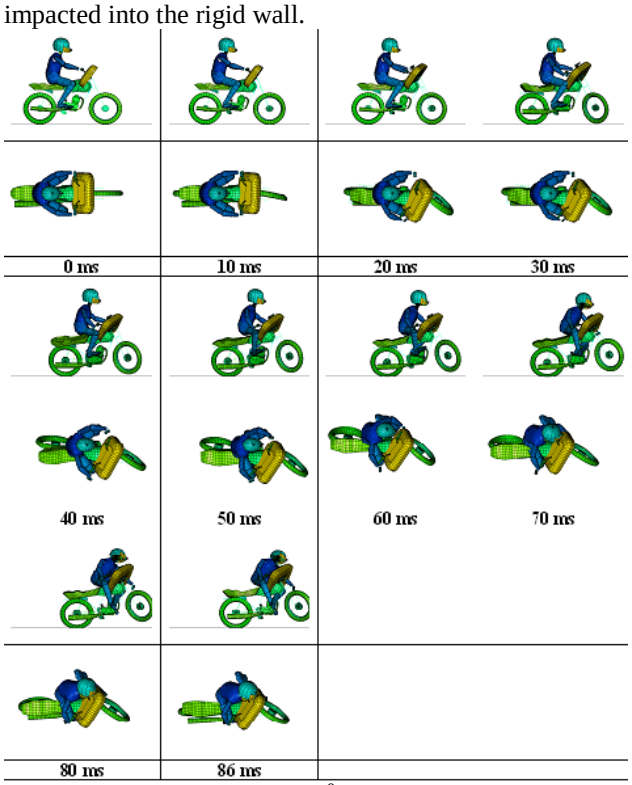


Figure 19 Motorcycle with 45^0 impacts - Base simulation

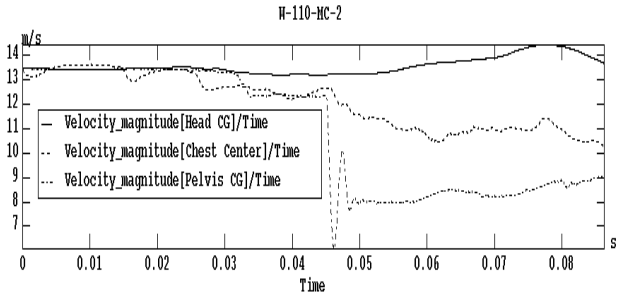


Figure 20 Motorcycle with 45^0 impacts - Velocity profile of MATD parts

As shown in Figure 18 and Figure 20, in both the cases of 90^0 and 45^0 angle of impacts respectively, the head CG velocity increased from the initial velocity due to the momentum transfer phenomenon. The pelvis velocity got reduced in both the cases because of its contact with the fuel tank and seat. The result of the chest slowing down was due to the reduction in the velocity of the pelvis.

Evaluation of a Backing Surface Effect

Initially, the airbag module was placed in between the handle bars. The base of the airbag was centered on the steering triangular member. Thus, the base of the airbag was kept parallel to the plane passing through the beams of the steering triangular member. The handle connected to the steering triangular member beams was passing below the airbag casing. This position of the airbag module was called as initial configuration shown in Figure 21. Two test runs were simulated to find out the effect of a backing surface. In first run the airbag was not included in the rigid wall definition and thus allowed to move beyond the rigid wall; while in second run, the airbag was included in the rigid wall definition so that it would not move beyond the rigid wall.

Effect of various sizes of airbags was studied in both the test runs. Mainly, there were two sizes of the airbags considered in this study. Those were smaller airbag of 110L and medium airbag of 142L size. In following section, 110L and 142L airbags results are given to highlight the backing surface effect. The airbag module was placed on the steering frame at the mid centre of the handle i.e. initial configuration. In both the test runs, the motorcycle was impacted into the rigid wall with 13.4m/s speed at right angle.

<u>Without backing surface</u> In this case, the velocity of the head CG of the rider just before impacting the rigid wall was not much reduced as compared to the base line simulation.

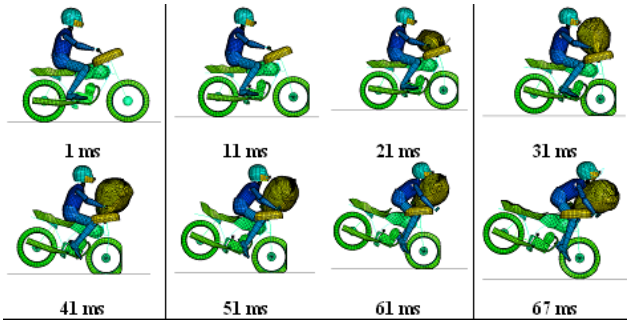


Figure 21 Barrier test simulation without backing surface for 110L airbag

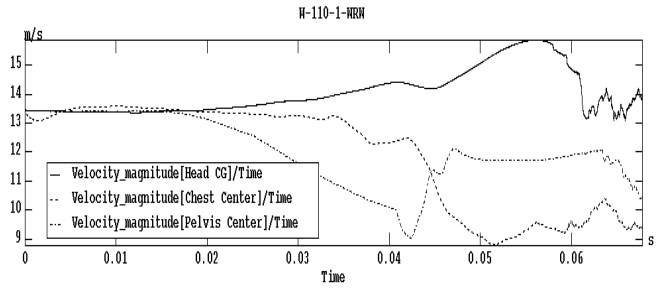


Figure 22 Barrier test simulation without backing surface for 110L airbag: Velocity profiles

Figure 21 shows that the dummy just rolled over the airbag for smaller airbag of 110L size at 67ms. As shown in Figure 22, the velocity of the Head CG just before impacting into the barrier was 13.8 m/s. It was observed

that the reduction in Kinetic energy of the Head CG was 13.75%. As seen in Figure 21, the airbag could not restrain the rider due to lack of support in terms of a backing surface. Thus, the purpose of mounting the airbag into the motorcycle got defeated due to lack of proper backing surface. In this case, a need of a backing surface for the airbag was felt to restrain the rider.

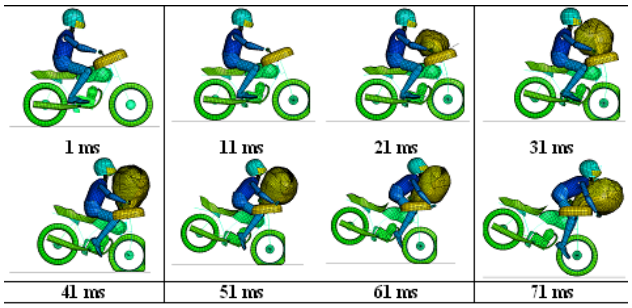


Figure 23 Barrier test simulation without backing surface for 142L airbag

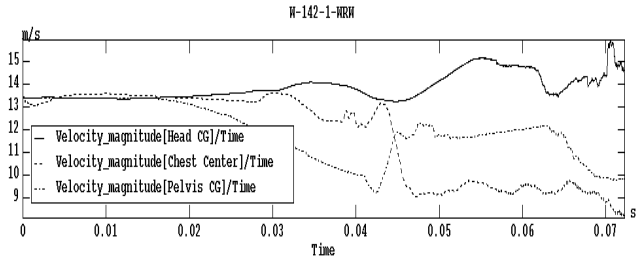


Figure 24 Barrier test simulation without backing surface for 142L airbag: Velocity profiles of MATD parts

As shown in Figure 23, it was observed that for 142L size airbag, the dummy just rolled over the airbag. Figure 24 shows, the velocity of the Head CG just before impacting into the rigid wall was 14.2 m/s. The reduction in kinetic energy of the Head CG was 11.21%. Likewise as in the earlier case with 110L size airbag; in this case also a need of a backing surface was felt to restrain the rider properly. Thus, without a backing surface the airbag did not provide the cushioning and restraining effect to the rider as required.

<u>With a backing surface</u> It was observed that a backing surface provided by the rigid wall led to the reduction in kinetic energy of the rider's head to some extent for all sizes of airbags considered.

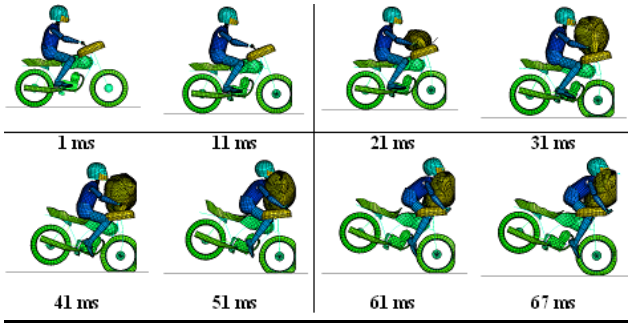


Figure 25 Barrier test simulation with backing surface-110L airbag-Simulations states

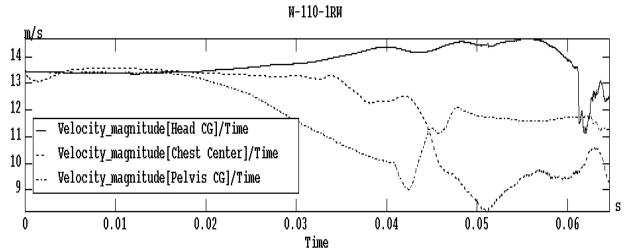


Figure 26 Barrier test simulation with backing surface-110L airbag- Velocity profiles

Figure 25 shows the snapshots of the simulation states for 110L size airbag. It shows that in the initial configuration the airbag got ejected upwards. The restrain type airbag became the trajectory type due to the pitching movement of the motorcycle as shown in Figure 25. The airbag got trapped in between the rider and the rigid wall. Thus, the rigid wall provided the backing surface in restraining the rider to some extent. At 67ms it shows that the rider was restrained from further moving forward. Figure 26 shows the velocity of the Head CG just before impacting into the barrier was 12.5 m/s. For smaller airbag of 110L size, it was observed that the reduction in kinetic Energy of the Head CG was 21.87 %. In this case, a need of a backing surface for the airbag was felt to restrain the rider properly in better way.

Figure 27 shows the snapshots of the simulation states for 142L size airbag. Here also, the airbag got trapped in between the rider and the rigid wall.

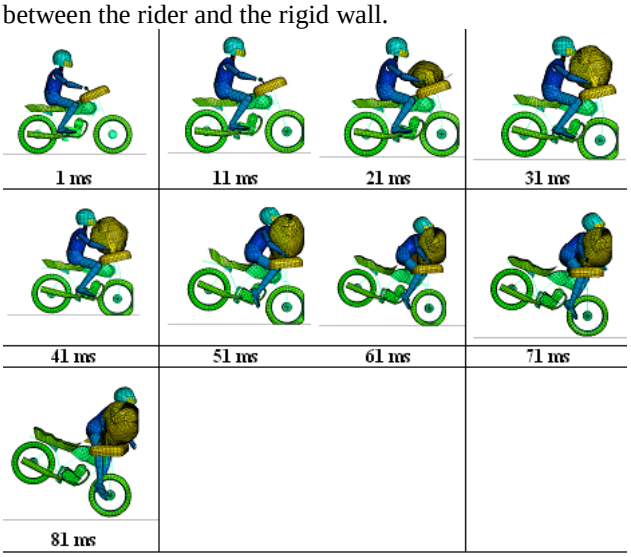


Figure 27 Barrier test simulation with backing surface for 142L size airbag

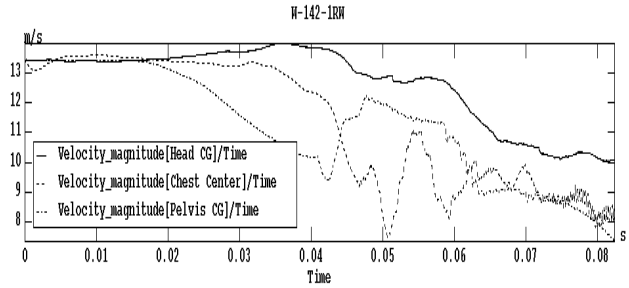


Figure 28 with backing surface for 142L size airbag

It is seen from Figure 28 that the velocity of the Head CG just before impacting into the barrier was 10.3 m/s. The reduction in kinetic energy of the Head CG was found to be 35.62 %. A need of backing surface within a motorcycle was felt, to restrain the rider effectively.

Alternate Arrangement

As discussed in earlier sections, it was felt that the airbag was not that much effective to restrain the rider with the initial configuration of the airbag module. Moreover, it was felt that it would be better to make use of a backing surface within the motorcycle itself rather than taking it from the opposing vehicle or the barrier. It was decided to use the airbag support base as a backing surface. Three options were tried for this arrangement called as alternate arrangement 1, 2 and 3. In the first case the airbag module was tilted such that the airbag inflation axis gets directed toward the dummy chest centre. In second case, the airbag module was shifted at the front by 200mm and upward by 50mm and tilted such that its inflation axis gets directed towards the neck./chin of the rider. In third Alternate arrangement, the axis of inflation of airbag was directed towards the chest center.

Alternate arrangement 1 The axis of airbag inflation was calculated by selecting a mid node of the casing box at the bottom side and a mid node at the top side of inflated airbag mesh directly coming out of the casing. A node at the middle of the chest and sternum facing the airbag called as chest center was selected as the point towards which axis of airbag inflation was directed. It was done by tilting appropriately the airbag with its casing relative to the top base frame of the front suspension. As shown in Figure 29, the airbag casing was allowed to overlap the fuel tank. As discussed earlier, although the thickness of the airbag casing in reality is 8-20mm but for the modeling purpose it was taken as 75mm. It was observed that after deployment of the airbag, the fuel tank also acted as a backing surface in the alternate arrangement of tilting the airbag module. Also the velocity and thus kinetic energy of the rider got reduced significantly due to the airbag restraining effect. Figure 29 shows the snap shots of the simulation states for 110L airbag in Alternate arrangement 1 configuration. It is seen that the rider got slid on the airbag pushing it towards left hand side. As shown in Figure 30, for 110L airbag, the velocity of the Head CG just before impacting into the barrier was 10 m/s. The fluctuations in velocity profile of the Head CG were due to sliding of the dummy on the airbag. Thus, the reduction in kinetic energy of the Head CG was found to be 37.5%. The results were encouraging compared to the initial configuration of the airbag module.

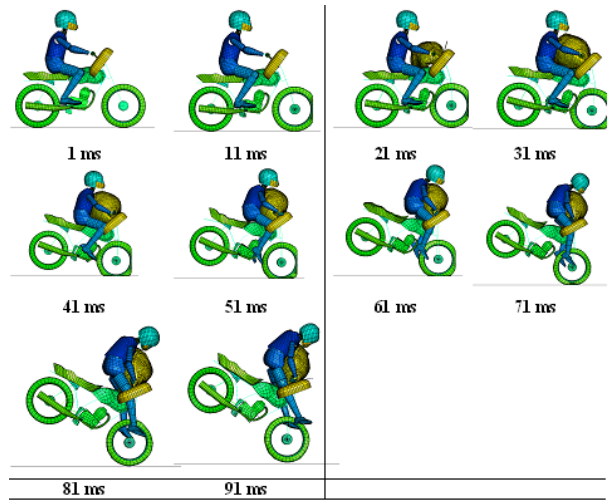


Figure 29 Alternate arrangement 1- 110L airbag – Simulation states

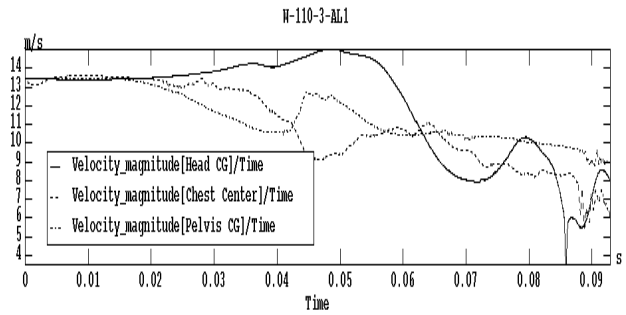


Figure 30 Alternate arrangement 1- 110L airbag- Velocity profiles

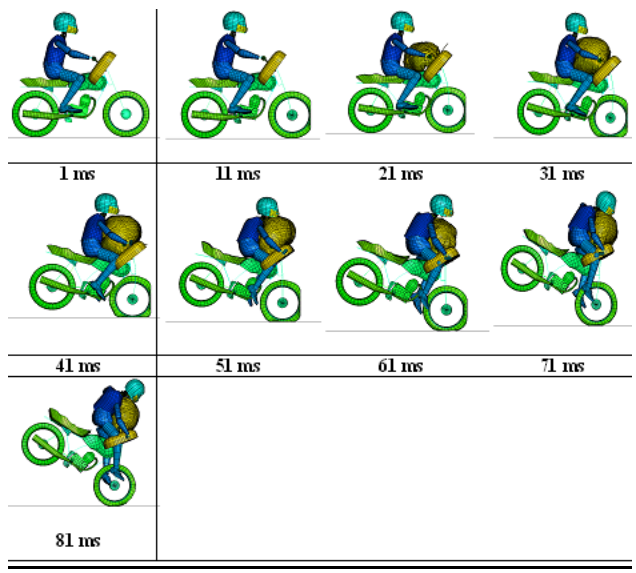


Figure 31 Alternate arrangement 1- 142L airbag – Simulation states

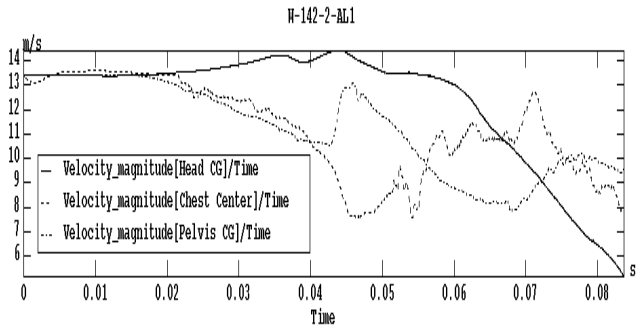


Figure 32 Alternate arrangement 1- 142L airbag- Velocity profiles

Figure 31 shows the snap shots of the simulation states for 142L airbag in Alternate arrangement 1 configuration. Here also, the rider tried to slide on the airbag. The airbag could not open properly due to smaller space available for its deployment. However, as seen in Figure 31, at 71 to 81 ms the rider was restrained by the airbag properly. Figure 32 shows, for 142L airbag, the velocity of the Head CG got reduced smoothly as compared to 110L size airbag. The velocity of the Head CG just before impacting into the barrier was 5 m/s. Thus, the reduction in kinetic energy of the Head CG was found to be 68.75%. The results were encouraging for 142L airbag as compared to the initial configuration of the airbag module in reducing kinetic energy of the Head.

In this case Neck Injury Criteria was calculated as per ISO 13232 standards. Table 2 shows relation between Abbreviated Injury Scale (AIS) and Maximum Neck Injury Index (NII)max.

Table 2
Neck combined loading injury severity probability as a function of *NII* [ISO 13232, 2005]

Severity Level	AIS≥ 1	AIS≥ 2	AIS≥ 3	AIS ≥4	AIS≥ 5
Minimum NII_{max}	1.06	1.86	2.29	4.73	4.73

Further, 153L and 180L sizes airbag were tested in Alternate Arrangement 1.

Table 3
Results for Alternate Arrangement-1

Alternate Arrangement -1						
Neck Injury Criteria (NIC) for MATD Neck				90 degree Impact		
Constants Value	Parameter	110L	142L	153L	180L	MC-Only
Fc* = 6.53kN	Fc	-3.305	-2.5	-4.04	-2.52	-1.48
Ft* = 3.34 kN	Ft	1.79	2.08	9.2	3.896	0.617
Mx*=62.66Nm	Mx	43.5	42.6	99	29.2	21
Me*= 58Nm	Me	-83.25	-60.4	-119.4	-78	-75
Mf*=204.2Nm	Mf	23	24	49.5	50	40.8
Mz*=47.1 Nm	Mz	18.3	17.6	13.95	10.8	2.7
NIC	NII_{max}	**1.788354**	**1.706905**	**3.028836**	**2.000728**	**1.485423**
File Name		W-110-3.pc	W-142-2.pc	W-160-32.pc	W-160-1.pc	W-110-MC.pc
Simulation end time, T		82ms	83ms	150ms	78	70ms
Head Velocity, m/s		10	5	5.4	8.1	16
% Reduction in KE		**37.5**	**68.75**	**66.25**	**49.375**	**0**
Base File		W-110-2.pc	W-142-1.pc	W-160-31.pc	W-110-3.pc	W-110-3.pc
AIS		**1**	**1**	**3**	**2**	**1**

As shown in Table 3, AIS value for 153L and 180Lsize airbag was 3 and 2 respectively. Therefore for the larger airbags of 153L and 180L size, the snap shots of the simulation states and the velocity profiles are not given here. However, their results in terms of the Neck Injury and reduction in kinetic energy are given in Table 3. It is observed that the 142L airbag reduced kinetic energy of the head CG by 68.75%. Also, in this case the NIC gave injury index of Abbreviated Injury Scale (AIS) 1 i.e. minor injury. The Neck Injury Criteria was given for the Alternate Arrangement 1 since the space available between the airbag and dummy was small. Therefore there was possibility of neck injury by deploying airbags of various sizes. It was found that 153L and 180L sizes airbag increased neck injury level to AIS 3 and 2 respectively.

<u>Alternate arrangement 2</u> It was found that the airbag could not get sufficient space to inflate properly in the Alternate arrangement 1. The airbag module was moved forward by 200mm and upward by 50mm in this configuration. It was placed on the top of the head light of the motorcycle. The airbag inflation axis was directed towards neck/chin of the dummy. Table 4 shows results of Alternate Arrangement 2.

Table 4
Results for Alternate Arrangement-2

Alternate arrangement 2- Airbag Inflation axis towards neck/chin

90 Degree with Alternate Arrangement 2- Airbag Inflation axis towards neck/chin

Constants Value	Parameter	110L	142L	153L	Motorcycle Only
Fc* = 6.53kN	Fc	-4.58	-6.2	-5.8	-1.48
Ft* = 3.34kN	Ft	0.516	2.49	3.48	0.617
Mx* = 62.66Nm	Mx	50.2	52.4	96.4	21
Me* = 58Nm	Me	-71	-108.2	-107.6	-75
Mf* = 204.2Nm	Mf	54	40.7	12	40.8
Mz* = 47.1Nm	Mz	4.92	16.5	36.4	2.7
Neck Injury Critera	**NII**	**1.190552**	**1.855636**	**2.37381**	**1.485423**
File Name		W-110-5-1.pc	W-142-4-1.pc	W-160-35.pc	W-110-MC.pc
Simulation end time T, ms		96	79	107	70ms
Head Velocity, m/s		4.32	4.58	3.4	16
% Reduction in KE		**73**	**71.375**	**78.75**	**0**
Base File		W-110-5.pc	W-142-2.pc	W-160-34.pc	W-110-3.pc
AIS		1	1	2	1

As compared to Alternate arrangement 1, the Alternate Arrangement 2 showed encouraging results in reducing kinetic energy of the rider's head. It was found that the velocity of the Head just before impacting into the barrier was 4.32 m/s for 110L size airbag. Thus, the reduction in kinetic energy of the Head CG was 73%. It was found that the velocity of the Head just before impacting into the barrier was 4.5 m/s for 142L size airbag. Thus, the reduction in kinetic energy of the Head CG was 71.37%. Moreover, it was found that the head did not move forward to impact into the rigid wall, but moved upwards along with the motorcycle. Also for the airbag size of 153L, the head CG velocity reduced to 3.4 m/s. Thus, the total reduction in kinetic energy of the head was found to be 78.25%. However, the neck injury increased to AIS 2 with 153L.

<u>Alternate arrangement 3</u> In this arrangement the airbag inflation axis was directed towards the dummy chest center for a better restraint of the rider.

Alternate Arrangement 3 configuration for 110L size airbag Figure 33 shows the snap shots of the Alternate Arrangement -3 simulation states for 110L size airbag. It can be seen from the snap shots that the airbag got sufficient space to inflate properly. To get more clarity of the crash event, the front and top views of snap shots are shown in Figure 33.

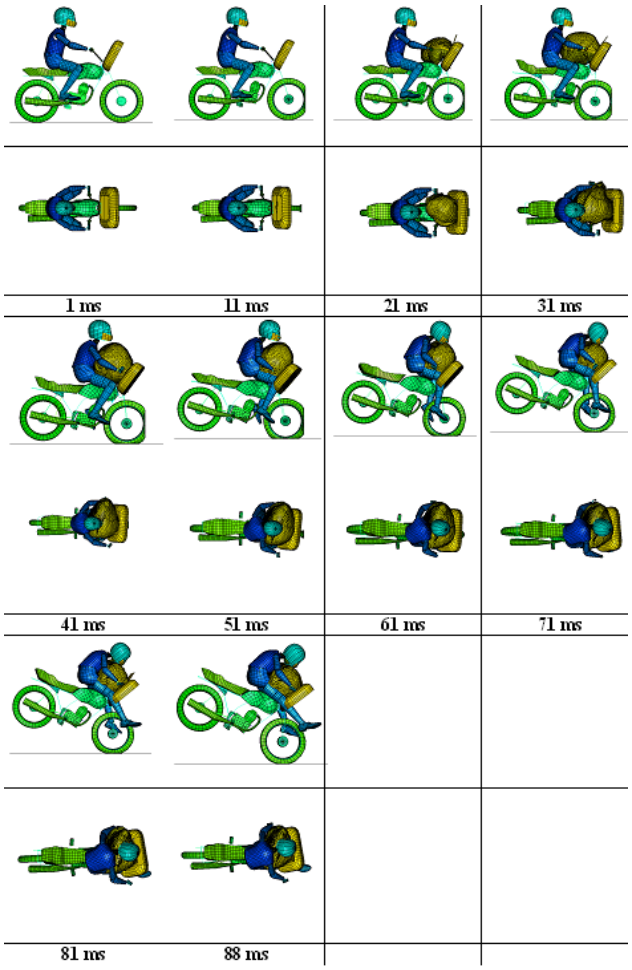


Figure 33 Alternate arrangement 3- 110L airbag- Simulation states

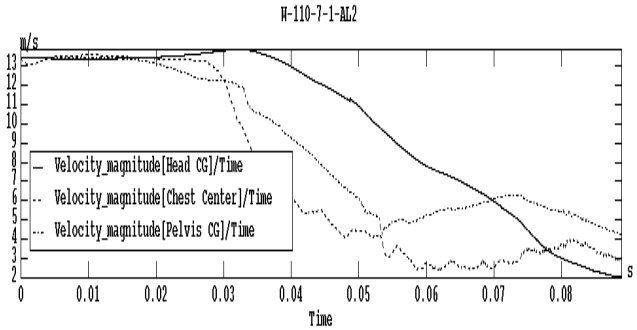


Figure 34 Alternate arrangement 3- 110L airbag- Velocity profiles

As shown in Figure 33, at 31 ms, the airbag almost got fully inflated. As it is directed towards the chest center so it restrained the chest and the pelvis up to the maximum extent. It is seen that the rider got bent above the airbag, thus its height of ejection got reduced. At 88ms, Figure 33 shows that the dummy was in the air and had no contact with the motorcycle. However, it rested on the deflating airbag as shown. This configuration of the airbag module provided the maximum restrain for the rider.

Figure 34 shows the velocity profile of the dummy parts. The dummy did not come in contact with the rigid wall till more than 88 ms. It was found that the velocity of the Head just before impacting into the barrier was 1.98 m/s for 110L size airbag. Thus, the reduction in kinetic energy of the Head CG was 87%.

Alternate Arrangement 3 configuration for 142L size airbag The following Figure 35 shows the snap shot of the simulations states for 142L size airbag. At 31 ms the airbag got sufficiently inflated when it hit the rider's chest and pelvis. At that time the rider was sliding on the seat and fuel tank. However, the airbag did not allow it to gain certain height due to the fuel tank.

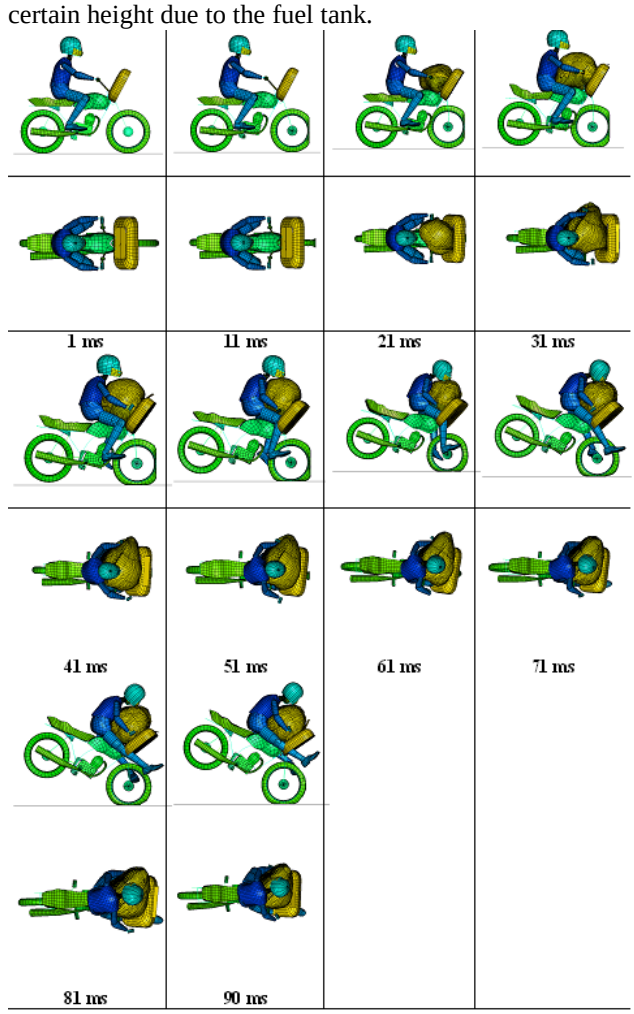


Figure 35 Alternate arrangement 3- 142L airbag- Simulation states

As shown in Figure 35, the rider after 41ms left the motorcycle and was completely restrained by the airbag. At 90ms the pelvis touched the fuel tank again. As shown, the rider did not touch the rigid wall up to 90ms. It is seen that the airbag tried to slip from the left hand side of the rider. But the rider's movement restricted the airbag from slipping further. The front tire did not leave the road as found in the base simulation. This is due to the dummy's entire weight falling on the airbag, which got

transmitted to the front wheel. Figure 36 shows the velocity profiles of the dummy parts. It was found that the velocity of the head just before its contact with the rigid wall was 2.4m/s. Thus, the reduction in kinetic energy of the rider's head was 85%. Also, the pelvis and chest velocity reduced gradually along with the head velocity.

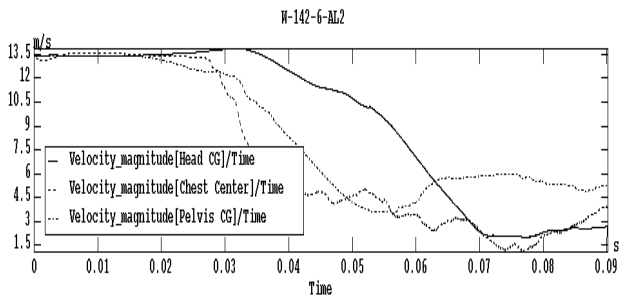


Figure 36 Alternate arrangement 3- 142L airbag- Velocity profiles

Table 5
Results of simulation for Alternate Arrangement 3

90 Degree with Alternate Arrangement -3					
Constants Value	**Parameter**	**110L**	**142L**	**153L**	**Motorcycle Only**
Fc* = 6.53 kN	Fc	-3.15	-3.675	-5.85	-1.48
Ft* = 3.34 kN	Ft	0.56	0.78	0.212	0.617
Mx* = 62.66 Nm	Mx	60	56.25	64	21
Me* = 58 Nm	Me	-64.5	-78	-71	-75
Mf* = 204.2 Nm	Mf	14.7	56	32	40.8
Mz* = 47.1 Nm	Mz	11.92	12.72	14.45	2.7
Neck Injury Criteria	NII	1.504023	1.486177	1.176471	1.485423
File Name		W-110-7-1.pc	W-142-6.pc	W-160-36.pc	W-110-MC.pc
Simulation end time T, ms		89	83	80	70ms
Head Velocity, m/s		1.98	2.4	7.4	16
% Reduction in KE		**87.625**	**85**	**53.75**	**0**
Base File		W-110-5.pc	W-142-4-1.pc	W-160-35.pc	W-110-3.pc
AIS		1	1	1	1

Table 5 shows that the 110L size airbag absorbed maximum of 87% kinetic energy of the rider's head whereas 142L airbag absorbed 85% and 153L airbag absorbed only 53%. It was found that 153L airbag could not provide proper restraining effect to the rider. Due to its larger volume the airbag got bent at its base and the dummy rolled over it. However, it was found that the NIC gave AIS value of 1 for all sizes of airbags in Alternate Arrangement 3.

Angular Impact

To study the effect of an angular impact, the rigid wall was titled to 45 degree with respect to the direction of motion of the motorcycle. The initial velocity of the motorcycle was kept at 13.4 m/s. The angular impact test simulations were carried out to find out the angular impact sensitivity on the airbags under the study. It was found that the motorcycle slid along the wall. Due to the sliding motion of the motorcycle, the airbag tries to push the rider further to leave the motorcycle. The left side of the rider slid along the inclined rigid wall. The rider tried to fall on the left side in between the motorcycle and the inclined rigid wall. The right leg got lifted due to this tendency of the rider. However, the head continued to move forward although its pelvis got resistance from the seat and the fuel tank. Kinetic energy of the head somewhat got reduced due to the airbag restraining. Its value was not as much as observed in the frontal impact scenario. The snapshots of the simulation states for the Alternate Arrangement 1 are not given for all the sizes of the airbags since the rider motion was more or less similar as discussed earlier. Table 6 shows the results of Alternate Arrangement 1 in 45 degree angular impacts.

Table 6
Angular Impact- 45 degree- Alternate Arrangement 1

45 degree Impact- Alternate Arrangement -1					
Constants Value	**Parameter**	**110L**	**142L**	**153L**	**Motorcycle Only**
Fc* = 6.53 kN	Fc	-2.375	-4.75	-4.36	-2.39
Ft* = 3.34 kN	Ft	0.855	0.51	0.848	0.78
Mx* = 62.66 Nm	Mx	52.2	61.45	52.8	51.6
Me* = 58 Nm	Me	-33	-49.3	-48.2	-37.73
Mf* = 204.2 Nm	Mf	24.6	30.345	36.6	10.05
Mz* = 47.1 Nm	Mz	11.36	17.5	13.65	6.6
Neck Injury Criteria for MATD Neck	NII	1.317187	1.18322	1.177719	1.339407
File Name		W-110-4.pc	W-142-3-1.pc	W-160-33.pc	W-110-MC-2.pc
Simulation end time T, ms		104	62	78	86
Head Velocity, m/s		6.9	5.1	8.6	13.67
% Reduction in KE		**49.52451**	**62.69203**	**37.08851**	**0**
Base File		W-110-3.pc	W-142-2.pc	W-160-32.pc	W-110-MC-1.pc
AIS		1	1	1	1

As shown in Table 6 the velocities of the Head CG just before impacting into the barrier were 6.9, 5.1 and 8.6 m/s for 110L, 142L and 153L size airbags respectively. Thus the reduction in kinetic Energy of the Head CG was 49.52%, 62.69% and 37.08 % for 110L, 142L and 153L size airbags respectively. In this case since the airbag came into the contact with the dummy from the initial stages of the airbag inflation, so in angular impact the airbag provided some restrain to the rider. However, this restraining was not as effective as observed in the frontal impact scenario. The reason was that, in angular impact the dummy tried to move straight forward whereas the airbag got titled along with the handle. So the backing surface in terms of the airbag base as envisaged could not be utilized due to turning of the handle. Thus there was no proper restraining of the dummy in angular impact of 45 degree.

In the Alternate Arrangement 2, the reduction in kinetic energy of rider's head was not that much as observed with the Alternate Arrangement 3. Therefore, the angular impact simulations were not carried out for Alternate Arrangement 2.

The following Figure 37 shows the snap shots of the simulation states for 110L size airbag in the Alternate Arrangement 3. As shown in Figure 37 at 20ms the hands got of the handle due to titling of the handle in 45^0angular impact. At 30ms the airbag got sufficiently inflated and came in between the hands of the dummy. At 40ms, the pelvis tried to leave the seat and right leg got lifted. At 50ms the dummy leant on the airbag and right leg left the foot rest. At 60ms motorcycle slid along the inclined wall and the dummy tried to get down from left side in between the motorcycle and wall. However, the head continued to move forward towards the wall with very

less restraining from the airbag. At 67ms the head touched the wall.

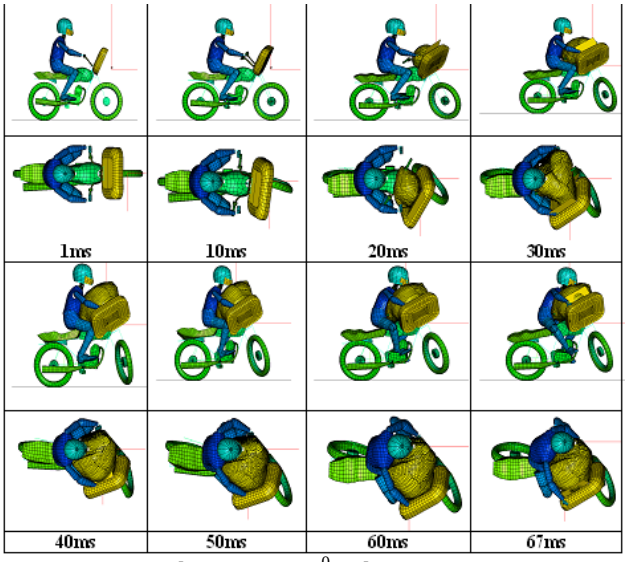


Figure 37 Angular impact-45^0: Alternate arrangement 3 - 110L airbag- Simulation states

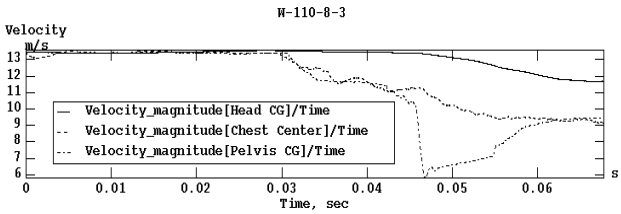


Figure 38 Angular impact-45^0: Alternate arrangement 3 - 110L airbag- Velocity Profiles

Figure 38 shows that the velocity of the head before its impact into the rigid wall was 11.8m/s. Thus, the reduction in kinetic Energy of the head was just 13.6%. The chest velocity was also not reduced much in this case. Thus, the smaller size of 110L airbag could not provide restraining in angular impact of 45^0 as observed in frontal impact.

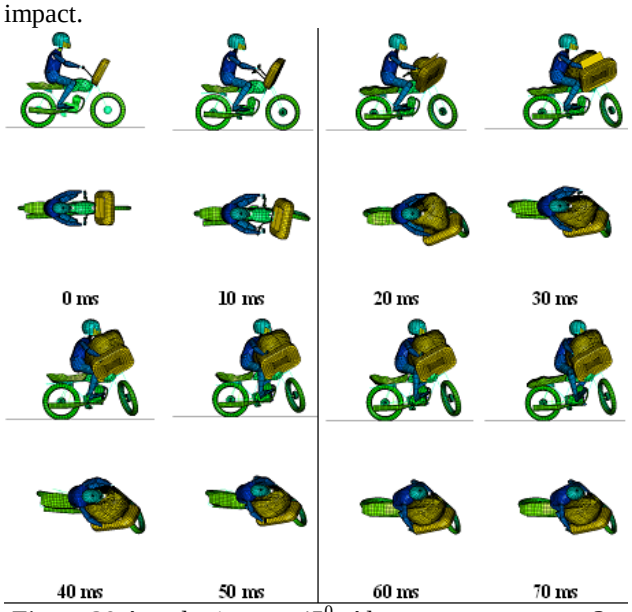


Figure 39 Angular impact-45^0: Alternate arrangement 3 - 142L airbag- Simulation states

Figure 39 shows that at 20ms the hand got off the handle. At 30ms the airbag got fairly inflated in between the hands of the dummy. At 40ms the airbag tried to provide restraining due to its larger size. At this time the right leg got lifted. The dummy continued to move forward. It touched the wall at 70ms.

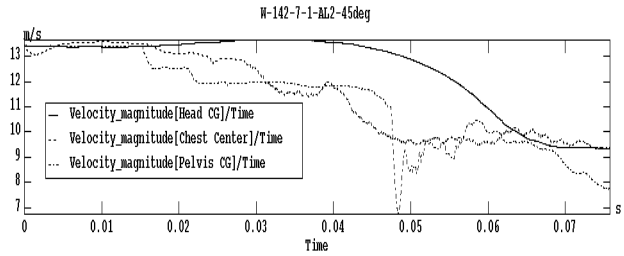


Figure 40 Angular impact-45^0: Alternate arrangement 3 - 142L airbag- Velocity profiles

As shown in Figure 40, the velocity of the Head CG just before impacting into the barrier was 9.2 m/s. Thus, the reduction in kinetic Energy of the Head CG was 32.69 %. This is better than that observed with the 110L size airbag.

Table 7
Percentage Reduction in kinetic Energy of Rider's Head in Barrier Test Simulations

Barrier Test Simulation	90^0 angle of impact			45^0 angle of impact		
Airbag Size	110L	142L	153L	110L	142L	153L
Initial Configuration	21.87	35.62	-	-	-	-
Alternate Arrangement 1	37.5	68.75	66.25	49.52	62.69	37.08
Alternate Arrangement 2 (Airbag axis towards neck/chin)	73	71.37	78.75	-	-	-
Alternate Arrangement 3 (Airbag axis towards chest)	87.62	**85**	53.75	13.6	**32.69**	-

Table 7 shows that in Alternate Arrangement 3 configuration the reduction in kinetic energy of the rider's head were 87.62% and 13.6% for 110L size airbag in 90^0 and 45^0 angles of impact respectively. This was the maximum reduction in kinetic energy of the rider's head that could be achieved. Due to smaller size it could not restrain the rider properly in angular impact. The airbag of 142L size could reduce kinetic energy of the rider's head by 85% and 32.6% in the frontal and angular impact simulations respectively as shown in Table 7. The large airbag of 153L size did not show positive results in the frontal impact barrier tests simulations. As shown in Table 7 it could reduce kinetic energy of the rider's head by 53.57%. Thus, the airbag of 142L size shows the promising results in mitigating the severe injuries or avoiding fatalities to the motorcycle rider in the frontal as well as angular impacts.

CONCLUSIONS

To evaluate the performance of the installed airbags into the Indian motorcycle, the barrier tests simulations of 90^0 and 45^0 angles of impact were run using PAM-CRASH™. The need of a backing surface in effectively restraining the rider by the airbag was investigated. It was found that the airbag module base can provide the required backing surface. The Alternate Arrangements of placement of the

airbag module were investigated. It is concluded that the airbag of 142L size is most promising in reducing kinetic energy of the rider's head in 90^0 and 45^0 angles of impacts by 85% and 32.69% respectively, when placed at the top of the head light of the motorcycle and its axis of inflation directing towards the chest center. The broad research question of suitability of an airbag in Indian motorcycle can be answered in affirmative.

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APPENDIX 1: MATD Neck Dynamic Tests [(2)]

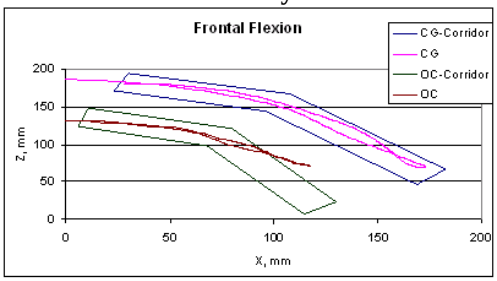

Figure 1-1 Frontal flexion Test- Trajectories of head CG and occipital condoyle

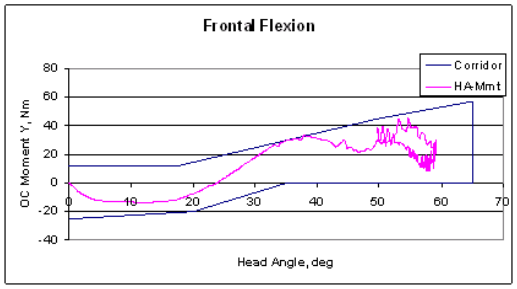

Figure 1-2 Frontal flexion Test- OC moment in Y-direction vs. Head angle

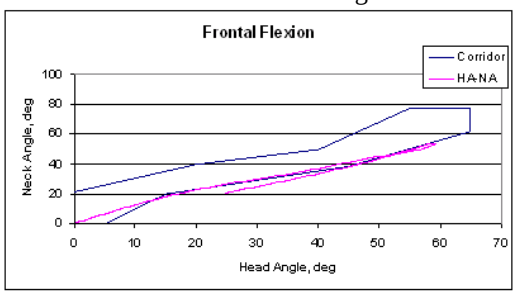

Figure 1-3 Frontal flexion Test- Head angle vs. Neck angle

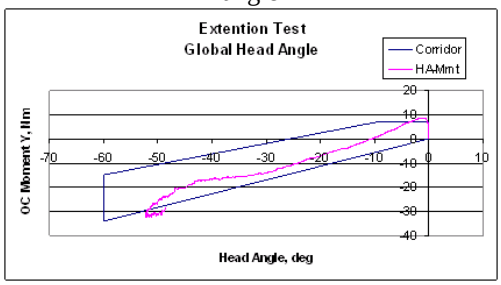

Figure 1-4 Frontal Extension Test: OC moment in Y-direction vs. Head angle

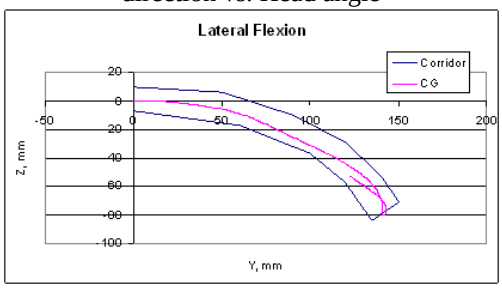

Figure 1-5 Lateral Flexion Test: Head CG Trajectory in Y-Z plane

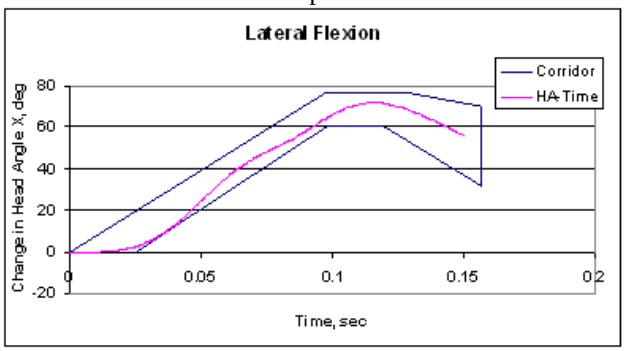

Figure 1-6 Lateral flexion Test: Time history of change of head angle