Thota et al. 2013. *Int. J. Vehicle Structures & Systems*, 5(3-4), 95-104
ISSN: 0975-3060 (Print), 0975-3540 (Online)
doi: 10.4273/ijvss.5.3-4.04

International Journal of Vehicle Structures & Systems
Available online at www.maftree.org/eja

CAE Simulation Based Methodology for Airbag Compliant Vehicle Front Protection System Development

Narasimha Thota[a,b], Jayantha Epaarachchi[b] and Kin Tak Lau[b]

[a]*CAD-CAE Consultants, Kilburn, Australia.*
Corresponding Author, Email: tnmurthy@cae-consultants.com.au
[b]*Centre of Excellence in Engineered Fibre Composites,*
University of Southern Queensland, Australia.

ABSTRACT:
In Australia, few hundreds of vehicle crashes involving animals are being recorded every year. In order to protect the headlights, radiator, engine and bonnet from getting damaged and also to improve the occupant safety, many cars are equipped with vehicle front protection system (VFPS) which are either 'over the bumper' or 'bumper replacement' type. VFPS alters the crush characteristics of the vehicle and in turn affects the airbag triggering characteristics. Hence, non-airbag compliant VFPS would cause more serious damage to the vehicle and potentially serious injuries to the occupants instead of offering additional safety in the event of animal strike or low speed crash. Though FPS is a very common accessory for all passenger vehicles in Australia, not much research is published in regards to the airbag compatibility and other requirements to comply with the safety standards and Australian design rules pertaining to the VFPS. Authors have devised a CAE simulation based methodology to develop airbag compliant VFPS requiring minimum number of vehicle crash tests. In this paper, authors have presented various aspects related to the VFPS design such as styling, mounting points, mounting brackets, material specifications, weight requirement and endurance life, along with the CAE methodology to acquire the airbag compliant VFPS.

KEYWORDS:
Vehicle Front Protection System; Airbag compatibility; ADR69; Occupant safety; Vehicle-animal collision

CITATION:
N. Thota, J. Epaarachchi and K.T. Lau. 2013. CAE Simulation Based Methodology for Airbag Compliant Vehicle Front Protection System Development, *Int. J. Vehicle Structures & Systems*, 5(3-4), 95-104. doi:10.4273/ijvss.5.3-4.04.

1. Introduction

As official database for vehicle accidents records only the accidents reported to the police, there was very limited data available on the vehicle-animal collision scenarios [1]. After analysis of the crash report database, it was reported that a total of 11636 vehicle crashes involving animals have occurred in Australia during the period from 2001 to 2005. Of these 61 were fatal, and 1049 were hospitalization crashes [2]. Due to the high prevalence of vehicle-animal collisions in Australian rural areas, many vehicles, not limited to recreational 4WD vehicles, are fitted with the wide variety of vehicle front protection system (VFPS) to protect not only the components under the bonnet but also occupants of the vehicle. VFPS also provides additional protection to the occupants and systems in the engine bay, when involved in low speed crashes. VFPS are categorized mainly into two types: 1 – Over the bumper (such as nudge bar and loop bar) and 2 – Bumper replacement type (Steel, Alloy and Plastic bull bars). Depending upon the type, design of the mounting brackets and mounting points, VFPS greatly influences the crush characteristics of the vehicle. Changes in the vehicle crush or deceleration pulse affect the airbag deployment characteristics. With the altered crash pulse, airbag may not get deployed when required, and it may get deployed when not necessary (very low speed impacts). In the former case, passenger safety is compromised as airbag did not get deployed during the serious accident. In the latter case, premature or delayed deployment of the airbag (punch out loading and membrane forces) itself may inflict serious injuries to the driver and passenger [3]. In a nutshell, if the VFPS is not compliant with airbags, it can make the vehicle not roadworthy, though is otherwise compliant with all safety standards and local design rules. Therefore, airbag compatibility is very crucial and mandatory requirement for all VFPS.

Many researchers have analyzed accident databases, studied the prevalence of bull bars and their detrimental effects on the pedestrian safety [1, 2, 4-10]. Australian standard AS 4876.1-2002 made a great emphasis on minimizing the pedestrian injury risk due to colliding with a vehicle equipped with a VFPS [11]. Every bull bar sold in Australia must comply with AS 4876.1-2002. Only few have studied and published the research related to the airbag compliance of the VFPS. Bignell [12] has conducted quasi-static and dynamic pendulum impact tests on 100 VFPS of various kinds, and concluded that VFPS require no further testing if the energy absorbed by over the bumper type loop bar is less than 4% of the total impact energy. In the case of bumper replacement type, the energy absorbed should be less than 8% of the total impact energy. In both quasi-static and dynamic pendulum tests, vehicle structure was not taken into consideration and VFPS was fitted to a rigid fixture. Vehicle front end structures were developed to meet the stringent occupant safety requirements. Airbag trigger algorithms are very complicated due to many airbags in the current day passenger cars and also due to many sensors mounted on desired critical locations on the car. Therefore, just energy absorption of the VFPS is not helpful to decide whether it is the airbag compliant or not. Sredojevic et al [13] has conducted experiments and recommended that lowest deceleration to trigger the airbag as 12g for 4WD recreational vehicles and 3.5g for Sedan passenger vehicles. Sredojevic et al. has not mentioned any information about the vehicle structure, sensor type and its location. Therefore, the outcome is vehicle specific and can't be applicable to decide whether VFPS have got the airbag compliance.

There are many aftermarket bull bars with the claim that they are airbag compliant. Most of the manufacturers declare them as airbag compliant by performing pendulum tests. Though the deceleration pulse obtained from the pendulum test provides some clue on the performance of the bull bar, that test is not enough to determine the airbag compatibility as the test does not take vehicle structure, sensors and their mounting points into consideration. Though many vehicle manufacturers provide VFPS as genuine accessories with airbag compatibility, there is no published research on the methodology and test specifications related to the air bag compliance. It is illegal to fit the bull bar to any passenger vehicles unless the vehicle with the bull bar is crash tested to meet the safety standards. Though most of the 4WD vehicle owners tend to go for some bull bar, revenue generated by the sale of VFPS, physical tests are not commercially viable, especially when bull bar manufacturers want to produce 5-6 types of VFPS for every vehicle. Due to the variation in the material, design of the fascia and tubular sections, mounting bracket design and mounting locations, to accomplish the airbag compatibility, for every variation of the bull bar would require many physical crash tests. Most importantly, the development process is iterative, as the first design itself may not be airbag compliant. Therefore, physical tests are commercially not viable. Another problem that poses great hindrance to the development of airbag compliant VFPS is vehicle manufacturers' secrecy pertaining to the airbag triggering algorithm.

In this paper, authors have presented limitations of the "trial and error" procedure by physical crash tests and systematic method, based on the virtual testing, to produce all variance of the VFPS with the airbag compatibility, for any vehicle with a minimum number of physical crash tests. Authors have also presented a real-life case in which all variance of bull bars were developed for a utility vehicle, with a great emphasis on mounting brackets and mounting locations.

2. Airbag compatibility

All passenger cars undergo rigorous crash tests to see the compliance with Australian standards and Australian design rules pertaining to the occupant and pedestrian safety and vehicle performance. Though NCAP safety ratings vary based on the performance of the vehicles, only those comply with the safety standards released to the market. Though initial days, premature deployment of the airbags have caused serious injuries, in conjunction with seatbelt restraints, they evolved to be most important safety features of the modern day passenger cars due to the robustness of the frontal crash sensing algorithms. These airbag triggering algorithms developed using the crash pulses obtained from the wide variety of physical crash tests in a simulated environment and also the pre-crash and post-crash data from the event data recorders of the vehicle [14-16]. For every vehicle equipped with airbags, manufacturers would define velocity thresholds for 'airbag no fire' and 'airbag must fire' scenarios [17-19]. For the utility vehicle under consideration, these velocity thresholds are given in the Fig. 1.

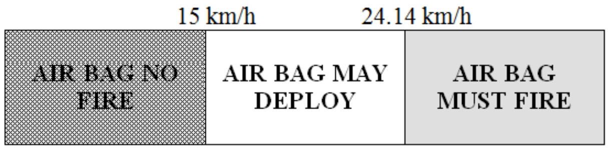

Fig. 1: Velocity thresholds for the airbag deployment

Irrespective of the type and whether any parts need to be removed to fit the VFPS, the modified vehicle must pass the following tests to consider it as air bag compatible:

a) **Air bag no fire test:** In this test, car with VFPS impacts a 40% offset rigid barrier at 15 km/h speed. During the impact, air bag should not fire and also the deceleration pulses obtained from two airbag sensors must pass the air bag triggering algorithm requirements. In some cases, authors have witnessed that deceleration pulses obtained from the G-sensors did not meet the air bag algorithm requirements, though air bag did not get deployed.
b) **Airbag must fire test:** In this test, car with VFPS impacts a 40% offset rigid barrier at 24.14 km/h speed. During the impact, the air bag must fire and the deceleration pulses obtained from two G-sensors must pass the air bag triggering algorithm.
c) **Australian Design Rule 69:** Every vehicle sold in Australia must meet the specific injury criteria [20, 21] as per Australian Design Rule 69. Test specification and performance criteria are given in the Table 1. Therefore, irrespective of the type of the VFPS, it is mandatory to prove that fitting the VFPS did not degrade the ADR69 test performance of the original vehicle.

Table 1: ADR69 test specification and performance criteria

Parameter	Criterion
Crash barrier	Full frontal rigid barrier to conform the SAE document J850 (1963) or FMVSS 208 rigid barrier
Speed of impact	48.3 km/h
Occupants	Belted Hybrid III dummies
Head injury	HIC ≤ 1000
Chest deflection	Sternal deflection must not exceed 76.2 mm
Chest deceleration	Must not exceed 60g
Femur load	Axial force must not exceed 10 kN

From the specifications, it is evident that airbag compatible VFPS development would require many vehicles for the crash tests. Authors have witnessed VFPS development program which took three crash tests for visual pass of the airbag no fire test and, unfortunately, the vehicle deceleration pulse did not pass the airbag deployment related crash sensing algorithm. Because of exorbitantly expensive crash test and vehicle costs, non-availability of prototype vehicles and cost of making production representative samples for every design iteration, development of airbag compliant VFPS becomes commercially non-viable. The development process becomes practically impossible, multi-variant VFPS for multi-variance models of the same vehicle. Therefore, authors have devised a CAE based methodology to develop airbag compatible VFPS (all variants of FPS to all variants of a vehicle) with only 3 physical crash tests. In the subsequent sections of the paper, devised methodology, selection of mounting points, and mounting brackets were presented.

3. CAE simulation based methodology

The CAE simulation based methodology for development of airbag compliant VFPS consists of the following major steps:

a) Development of the baseline design of VFPS and simplified crash simulations to perform dynamic tests for the selection of the baseline design for the VFPS mounts.
b) Development of correlated finite element (FE) model of the full vehicle.
c) Finalization of the FPS design with full vehicle CAE crash simulations.
d) Full vehicle physical crash tests as per the specifications.

3.1. Baseline design of the VFPS

Automotive engineers and researchers worldwide have been working on improving the pedestrian safety of the passenger cars and developed innovative designs from bumper spoilers to outward opening bumper airbags [22]. Modern passenger cars are aesthetically very appealing on top of meeting occupant safety standards. Therefore, contours of the VFPS must conform to the profile of the vehicle. During the concept stage of the VFPS design itself, stylist and designers must consider all the guidelines provided in the AS 4876.1-2002 so that VFPS does not adversely affect the driver's visibility, engine cooling, accessibility of vehicle recovery points and performance of the headlamps. Stylists should also incorporate semi-rigid foam embellishments for the fascia and tubular sections to ameliorate the aesthetics and to improve the energy absorbing characteristics and pedestrian safety performance of the VFPS.

Load bearing capacities of the axles, other accessories and options of the vehicle and Gross Vehicle Mass (GVM) greatly influence the maximum allowable weight for the VFPS. Therefore, enough caution should be exercised so that the VFPS weight has to be kept well below the evaluated maximum allowable weight. Mounting points provide the rigidity to the VFPS. For some vehicles in the market, over the bumper type VFPS were fitted utilizing the sheet metal components such as headlamp support and radiator support. In some cases, holes available on the plastic parts were used for mounting. Such mountings of the VFPS can cause considerable damage to the radiator and headlamps even during the low speed collisions. Therefore, adequate caution must be exercised in the selection of mounting points. Front end of the chassis (in the single-hat or double-hat crush-can) is one of the best locations to mount the VFPS. Required inputs for the development of the VFPS baseline design were summarised in the Fig. 2.

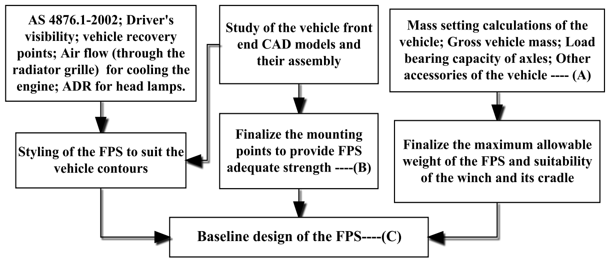

Fig. 2: Inputs for the development of VFPS baseline design

After selecting the mounting points, development of the VFPS mounts become an easy task. Design configurations such as plate with a fold, corrugated box and box section with weak points are suitable for mounting bracket design. Simplified crash simulations equivalent to dynamic pendulum tests would be very useful to select the baseline design of the VFPS mounts. The procedural steps were as shown in the Fig. 3. This process is very beneficial and greatly reduces the number of full vehicle crash simulations required

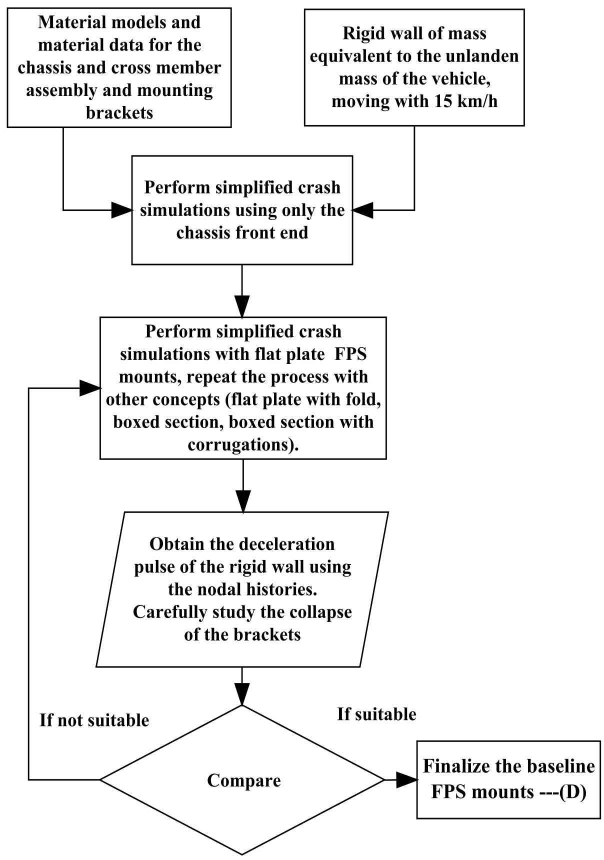

Fig. 3: Simplified crash simulations equivalent to dynamic pendulum tests to finalize the baseline VFPS mount design

3.2. Correlated full vehicle FE model development

Most of the vehicle manufacturers develop correlated FE model of the vehicle for various compliance tests in the virtual environment to exploit the benefits offered by the CAE technology. These models can be directly utilized for the full vehicle crash simulations pertaining to the airbag compatibility (airbag no fire, airbag must fire and ADR 69 test). If not available, correlated FE model of the vehicle can be developed, and procedural steps for the same were shown in Fig. 4.

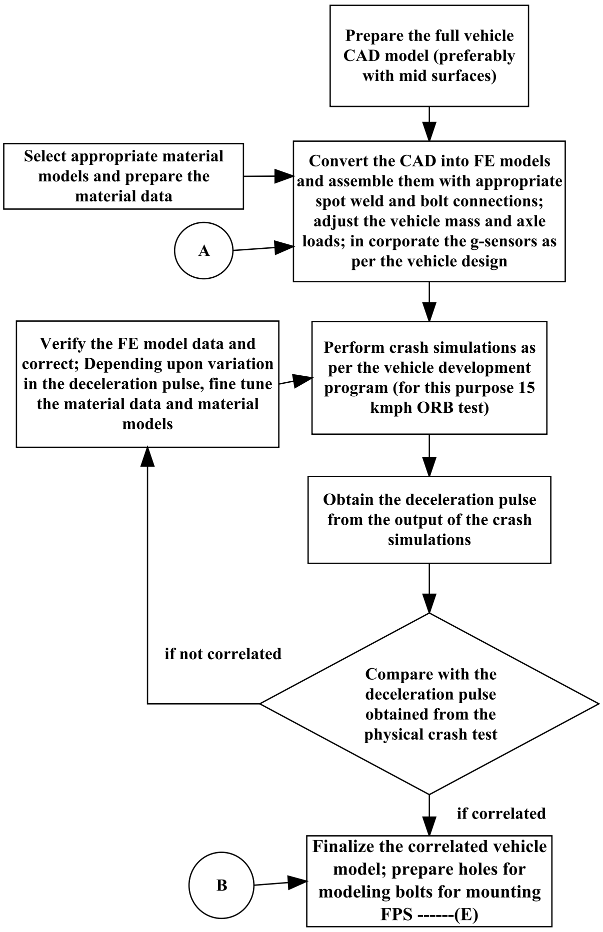

Fig. 4: Procedure for development of the correlated FE model of the full vehicle

3.3. Full vehicle CAE crash simulations

As performing full vehicle crash simulations is very crucial step in the airbag compatible VFPS development, procedural steps shown in Fig. 5 must be followed strictly. Every crash simulation, from the nodal time histories, deceleration pulses obtained for the nodes representing the front sensor and ECU sensor must be sent to vehicle manufacturer or airbag developers to review the airbag compliance of the VFPS. As dynamic tests were already carried out to select the appropriate design of the VFPS mounts, the airbag compatible VFPS mounts can be developed with very minimum (2-3) full vehicle CAE simulation iterations.

3.4. Full vehicle physical crash tests

Virtual tests are only useful to gain confidence in the design and results obtained from these simulations are not useful to release the VFPS as an airbag compliant accessory into the market. Therefore, the final step is to carry out physical crash tests as per Fig. 6 to attain the ADR 69 or airbag compliance.

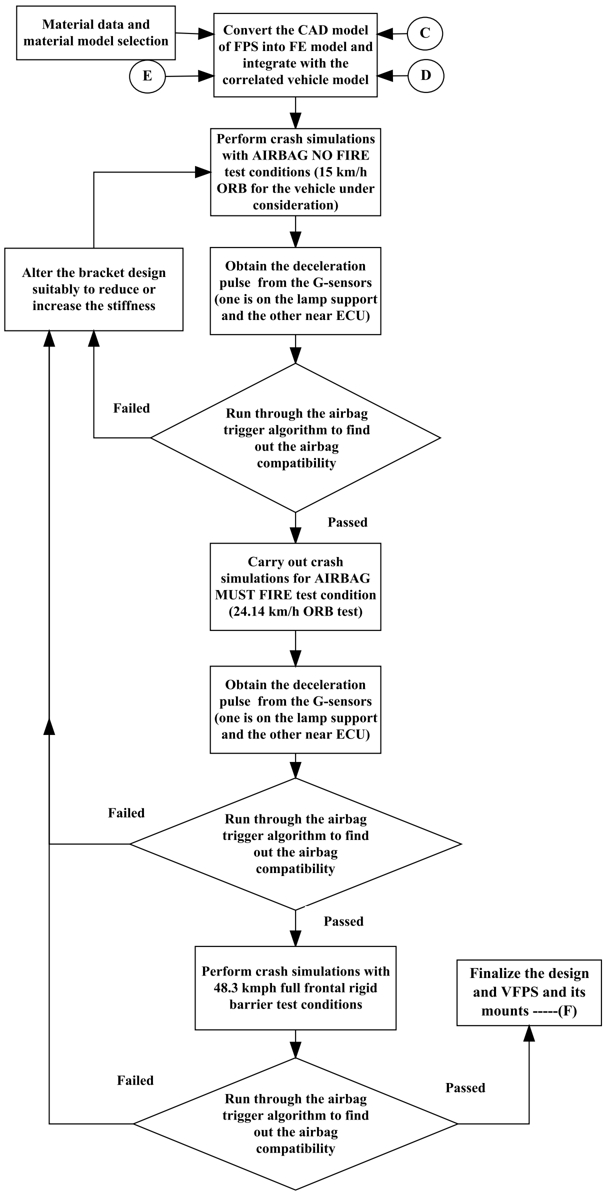

Fig. 5: CAE crash test protocol for accomplishment of the airbag compliant VFPS mounts

Authors have developed ADR 69 compliant or airbag compatible VFPS for many passenger vehicles on top of the proposed methodology. Following the same method, irrespective of the number of variants of vehicle, all variants of ADR compliant FPS (Steel bull bar, Alloy bull bar, Alloy nudge bar, Alloy loop bar and plastic loop bar) were developed with the minimum number of physical crash tests. A case study demonstrates the significance of the devised CAE simulation based methodology.

4. Results and discussions

4.1. Mass setting calculations and selection of the mounting locations

In order to demonstrate the efficacy of the devised method, typical recreational utility vehicle was considered for development of the VFPS. Normally vehicle manufacturers provide the correlated FE model of the vehicle model. The vehicle has got driver and front passenger airbags. Taking GVM, unladen weight, load capacity of the axles and other options & accessories into consideration, it was found that front axle has got 45 kg allowance. Therefore, authors have aimed at developing airbag compatible VFPS with maximum weight 35 kg. As winch adds at least 45 kg weight on the front axle, it was not considered in the design and development. After careful study of the front end vehicle structure, 5 mounting points, as shown in Fig. 7, were selected on each side of the vehicle (3 on the FRAME_OUTER and 2 on the BRACKET_HOOK) for fitting the VFPS.

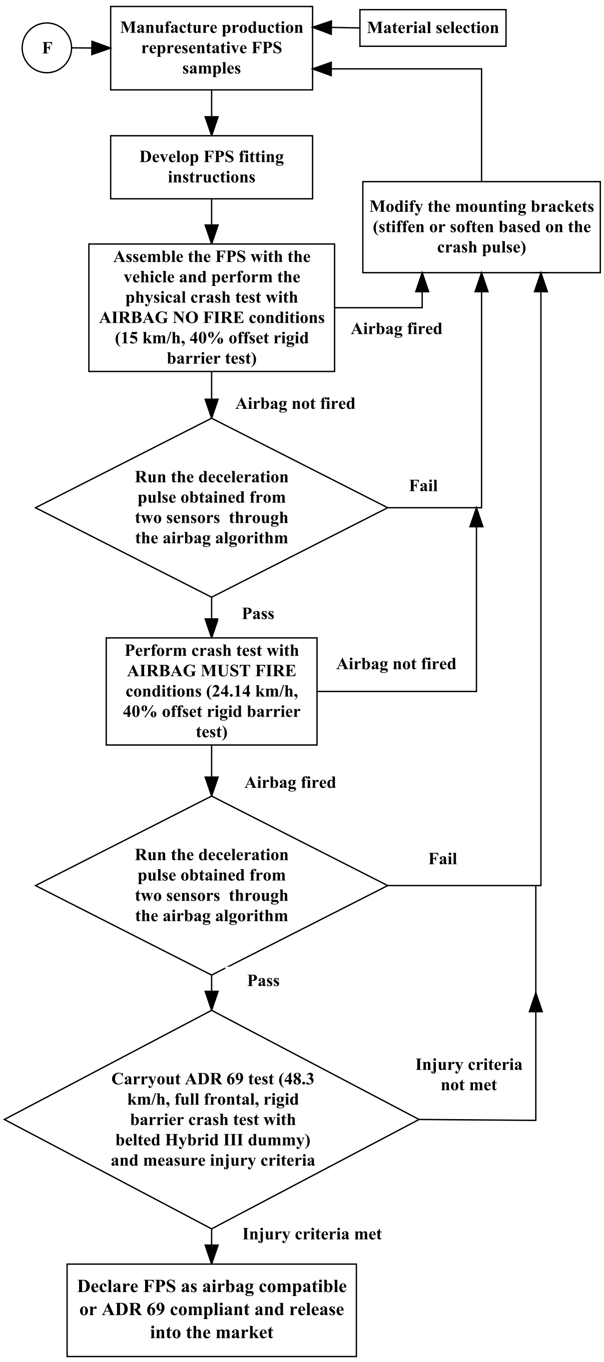

Fig. 6: Full vehicle physical crash test protocol for accomplishment of the ADR 69 or airbag compliance to the VFPS

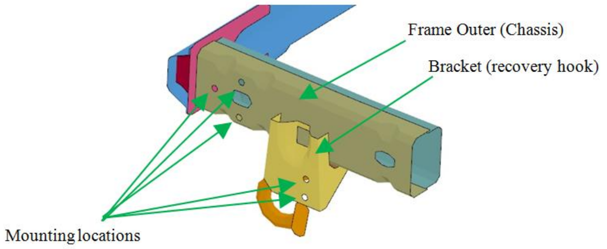

Fig. 7: Selected mounting locations for fitting the VFPS

4.2. Simplified crash simulations to finalize the baseline design of the FPS mounts

As the mounting points are on the chassis, it is possible to develop many configurations of the mounting brackets. Simplified crash simulations which are equivalent to dynamic pendulum tests were performed. In these simulations, front-end of the chassis and cross beam assembly were considered for the analysis. Mid-surfaces of the components were utilized for the FE model. Material data used in the analysis were given in Table 2. MAT_PIECEWISE_LINEAR_PLASTICITY (MAT_024 in LS-DYNA) material model was used. SURFACE_TO_SURFACE contact interface definition was used. Simplified vehicle assembly with a mass of 1736 kg moving with the speed of 15 km/h was impacted over a rigid wall to simulate the effect of whole vehicle mass and airbag no fire test conditions. Simplified crash simulation set-up was shown in Fig. 8. Various stages of chassis-cross beam assembly crushing were shown in Figs. 9(a)-(d). LH side of the assembly was only shown due to symmetry of the assembly.

Table 2: Material properties for simplified and full vehicle crash simulations

Component	Chassis	FPS mounts, Steel bull bar fascia and tubular sections	Bump-terettes (Semi-rigid PU)	Alloy fascia and tubular sections
Young modulus GPa	206.0	215.0	0.39	70.0
Density kg/mm^3	7.85×10^{-6}	7.85×10^{-6}	9.27×10^{-7}	2.6×10^{-6}
Poisson ratio	0.3	0.3	0.35	0.27
Yield stress GPa	0.24	0.225	-	-

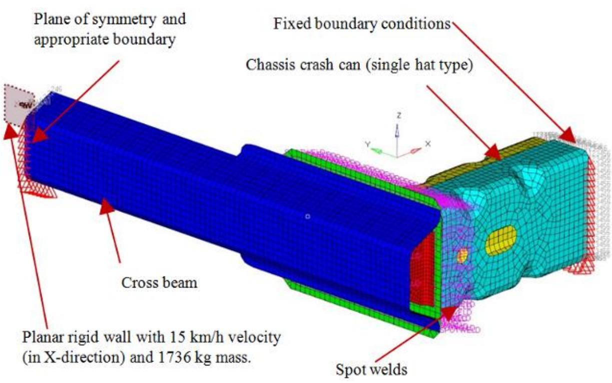

Fig. 8: Set up of the simplified crash analysis

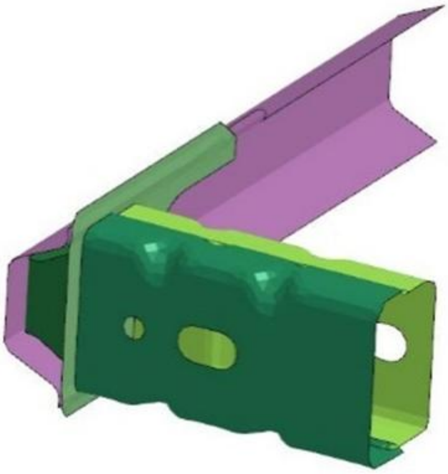

Fig. 9(a): Chassis & cross member crushing at t = 0 ms

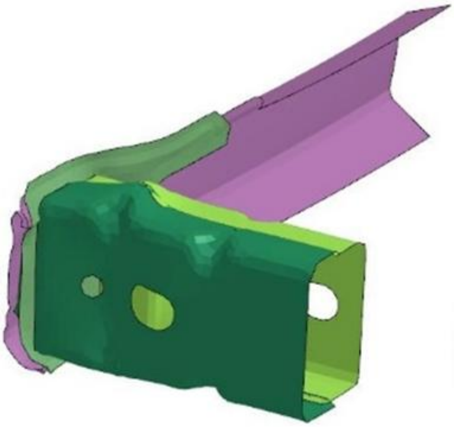

Fig. 9(b): Chassis & cross member crushing at t = 8.4 ms

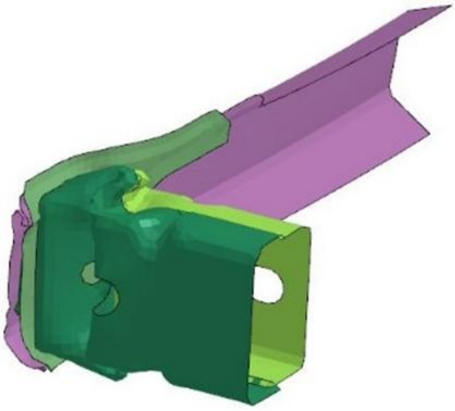

Fig. 9(c): Chassis & cross member crushing at t = 17 ms

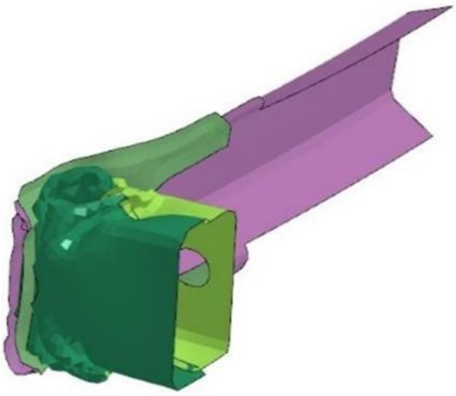

Fig. 9(d): Chassis & cross member crushing at t = 30 ms

In order to select an appropriate configuration that nullifies the effect of stiffening the crash-can, flat plate, flat plate with a fold and corrugated box section designs for the FPS mounts, as shown in Figs. 10(a)-(c), were considered. Simplified simulations were carried out for these configurations. FPS mount with a corrugated box section design became infeasible owing to the higher weight, complexity in design and many design variables. Deceleration pulses from the time histories of the node created on the rigid wall were extracted for the flat plate and flat plate with a fold mount designs. Fig. 11 shows a comparison of these pulses with the chassis-cross member assembly without mounts. Addition of the brackets to the chassis altered its crush characteristics by increasing its stiffness. The fold provided in the mount is working to rebuild the crush characteristics of VFPS mount and chassis assembly. Hence, this mount configuration was considered for the baseline design of the VFPS owing to the simplicity and ability to fine tune the deceleration pulse.

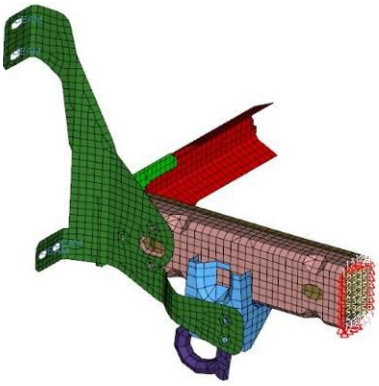

Fig. 10(a): Flat plate FPS mount configuration

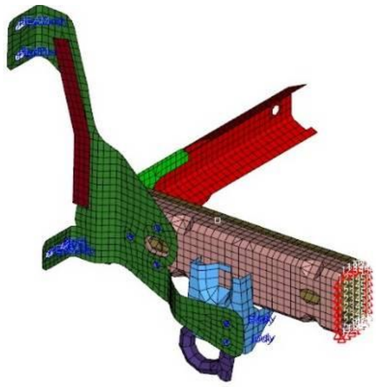

Fig. 10(b): Flat plate with a fold FPS mount configuration

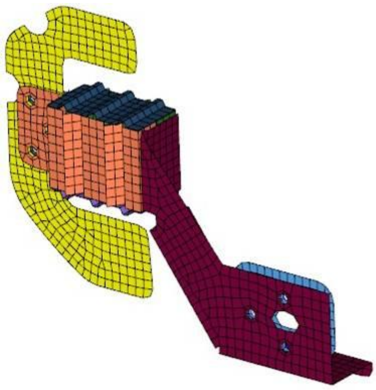

Fig. 10(c): Corrugated box section FPS mount configuration

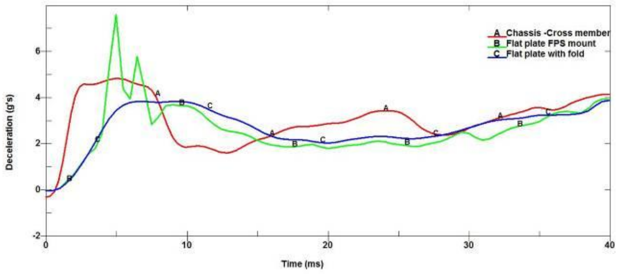

Fig. 11: Deceleration pulses comparison for FPS mount designs with baseline chassis-cross member assembly

4.3. Full vehicle crash CAE simulations

CAE crash simulations were carried out for airbag no fire test conditions by integrating the FE model of the baseline steel bull bar with correlated full vehicle model. Rigid barrier FE model in LS-DYNA was used in the simulations with 40% offset. Bolts were modelled with beam and spider connections. Stages of the impacting vehicle were as shown in the Figs. 12(a)-(d). Deceleration pulses obtained from the front and ECU sensors were sent to the vehicle manufacturer for review of airbag compatibility. As the first design of mounts were found to be non-compatible with airbag, further CAE simulations of full vehicle model by varying the size and location of the fold of the FPS mount were carried out for airbag no fire test conditions.

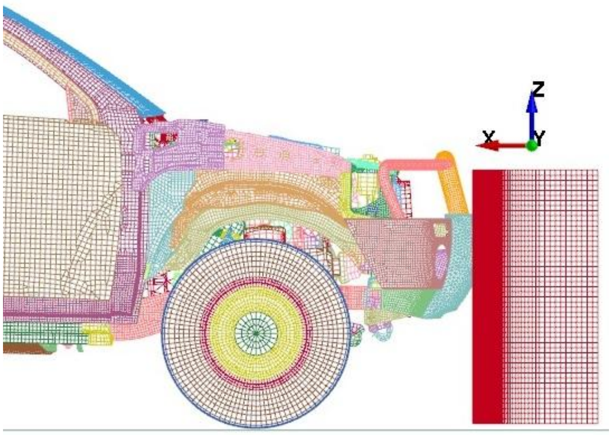

Fig. 12(a): Impact behaviour of vehicle fitted with bumper replacement bull bar for airbag no fire test conditions at t = 0 ms

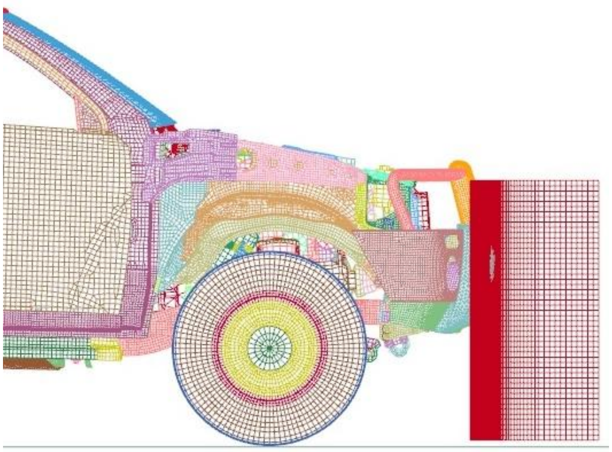

Fig. 12(b): Impact behaviour of vehicle fitted with bumper replacement bull bar for airbag no fire test conditions at t = 20 ms

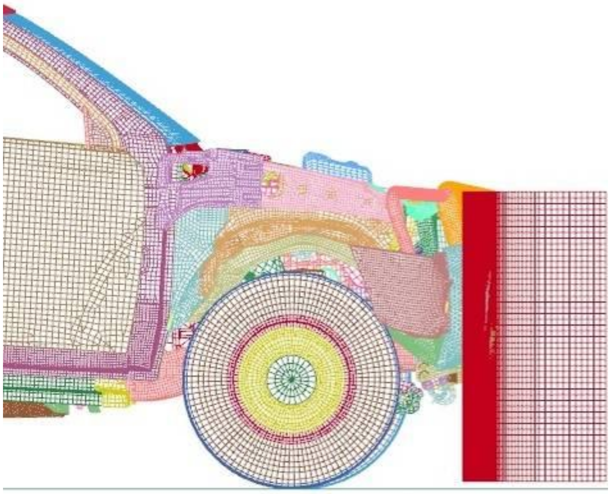

Fig. 12(c): Impact behaviour of vehicle fitted with bumper replacement bull bar for airbag no fire test conditions at t = 96 ms

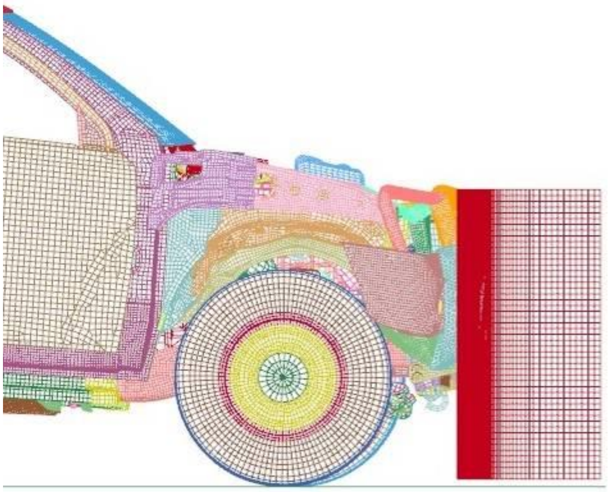

Fig. 12(d): Impact behaviour of vehicle fitted with bumper replacement bull bar for airbag no fire test conditions at t = 125 ms

Four variations of the FPS mounts and outcome from the airbag crash sensing algorithm were shown in Figs. 13(a)-(d). Figs. 14(a)-(b) show a comparison of their cross-sections. Deceleration pulses obtained from the front and ECU sensors for airbag no fire test conditions for all four FPS mounts were as shown in Figs. 15(a)-(b). It is imperative to note that the FPS mount # 4 has got very little differences when compared to the FPS mount finalized through the simplified crash simulations. Using the finalized FPS mount #4, CAE simulation with airbag must fire test conditions (40% offset rigid barrier, 24.14 km/h impact speed) was carried out. Deceleration pulses obtained from the analysis, as shown in Fig. 16, were analyzed by using airbag crash sensor triggering algorithm. The very first iteration, FPS mounts have accomplished the airbag must fire requirements. Similarly, deceleration pulses obtained from the CAE simulation iteration as per ADR 69 test specifications were analyzed and found that FPS mounts were ADR 69 compatible. In the case all four FPS mounts were found to be non-compatible with the airbag, outcome on these variations would have been very helpful to develop potentially suitable design for the airbag compliance.

Fig. 13(a): FPS mount #1 design

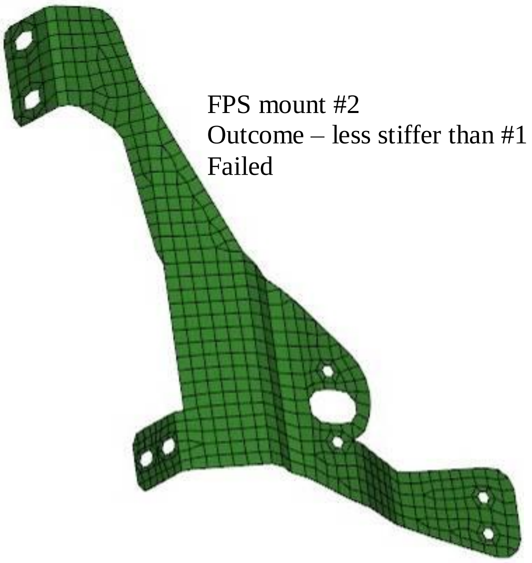

Fig. 13(b): FPS mount #2 design

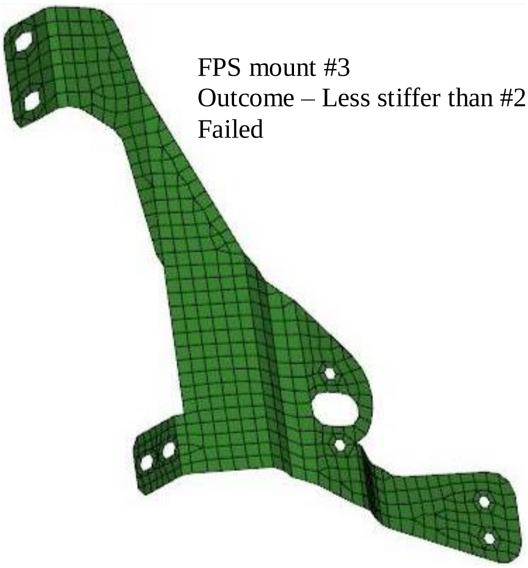

Fig. 13(c): FPS mount #3 design

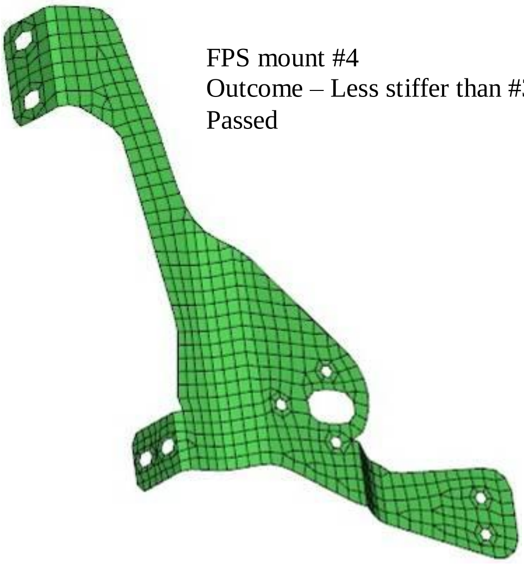

Fig. 13(d): FPS mount #4 design

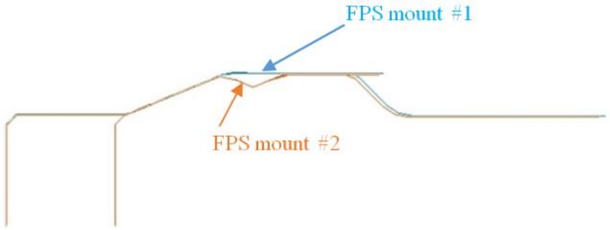

Fig. 14(a): Cross sections of FPS mounts #1 and #2

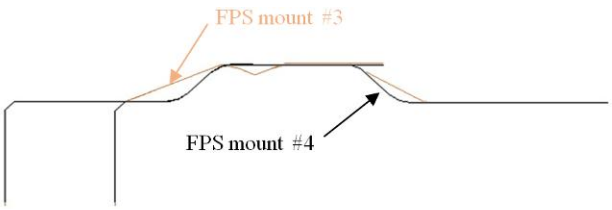

Fig. 14(b): Cross sections of FPS mounts #3 and #4

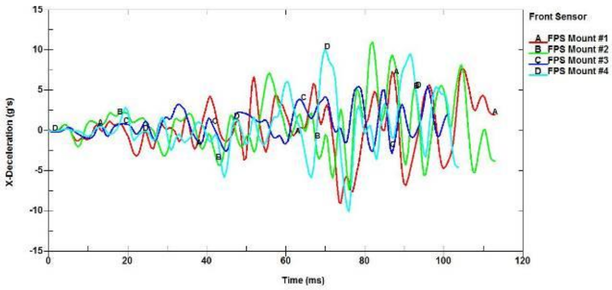

Fig. 15(a): Deceleration pulses from the front sensor for the airbag no fire test conditions

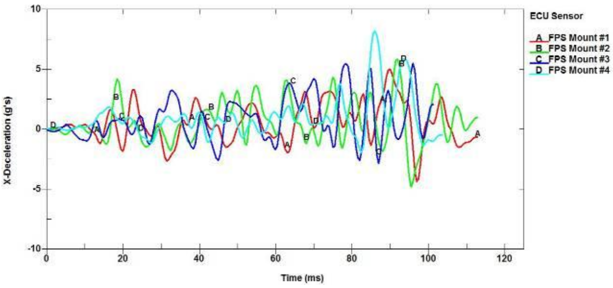

Fig. 15(b): Deceleration pulses from the ECU sensor for the airbag no fire test conditions

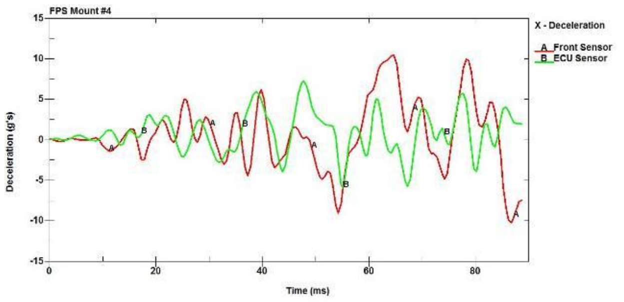

Fig. 16: Deceleration pulses from the front and ECU sensors for the airbag must fire test conditions

4.4. Problem associated with the development of multi-variant FPS for multi-variant vehicles

The vehicle considered for the case study has got eight variants of unladen weight ranging from 1736 kg – 1880 kg. The goal was to produce 2 bumper replacement type and 3 over the bumper type variants of VFPS. We need at least 8×5×3 = 120 vehicles for physical crash tests to demonstrate airbag no fire, airbag must fire and ADR 69 compliance. To minimize the number of physical crash tests, authors have decided to use the same brackets and mounting points to all variants of the VFPS for all vehicle variants. A new VFPS mount design, as shown in Fig. 17, was developed using the VFPS mount #4 without altering its crash characteristics. The integration of this FPS mount on the vehicle chassis-cross beam model was shown in Fig. 18.

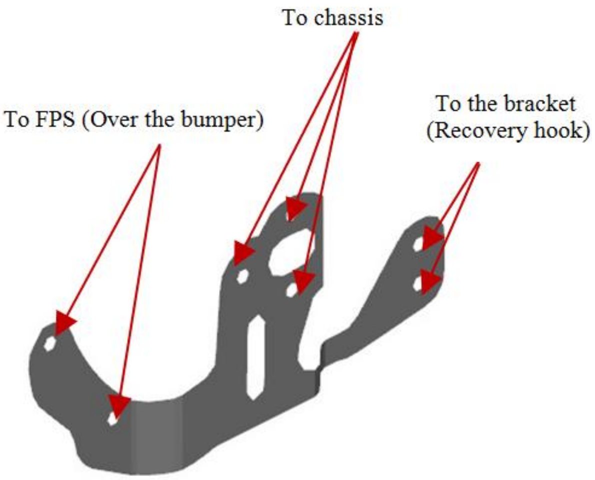

Fig. 17: Over the bumper type FPS mount

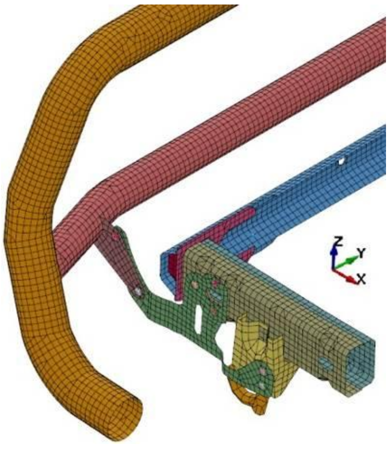

Fig. 18: Over the bumper type FPS mount and it's mating parts

As there were no differences in the vehicle front-end structures of all variants and the same mounting points & mounts with the same crash characteristics were used, the following CAE simulations and physical crash tests would suffice to prove the airbag compliance of all VFPS mounts for all vehicle variants:

a) Airbag no fire test - Vehicle with lowest unladen mass fitted with lightest variant VFPS.
b) Airbag no fire test - Vehicle with highest unladen mass fitted with the heaviest variant VFPS
c) Airbag must fire test - Vehicle with highest unladen mass fitted with the heaviest variant VFPS.
d) ADR69 test - Vehicle with highest unladen mass fitted with the heaviest variant VFPS.

Correlated model was adjusted to emulate the heaviest variant of the vehicle and remaining CAE simulations were carried out. For every simulation nodal time histories, deceleration pulses were elicited and sent for the review. All five variants have passed the airbag crash sensing algorithm and theoretically qualified as airbag compatible or ADR69 compliant.

5. Conclusions

CAE based simulations proved very beneficial in the development of the airbag compliant VFPS. Irrespective of whether the VFPS is over the bumper or bumper replacement type, fitting VFPS to the vehicle can undoubtedly alter the vehicle crush characteristics. Therefore, full vehicle crash tests are mandatory for proving the airbag compliance of the VFPS. Dynamic pendulum impact tests do not take into account of the vehicle parts onto which VFPS is mounted. Therefore, it is not possible to judge the airbag compliance based on the deceleration pulse obtained from the pendulum tests. Simplified crash simulations proposed by authors address the shortcomings of dynamic pendulum test. These simulations are simple and not computationally demanding. Most importantly, airbag compatible and ADR 69 compliant VFPS were successfully developed using the devised CAE simulation based methodology.

ACKNOWLEDGEMENTS:

Principal author profusely thanks Ms. Lakshmi, Mr. Baskaran and Mindglow India Pvt. Ltd., Bangalore for providing resources & support and also thanks Mr. K. Srinivasa Rao, Chairman of Amerigo Structural Engineers Pvt. Ltd., Bangalore for providing necessary funds for successful completion of the project.

REFERENCES:

[1] R. Attewell and K. Glase. 2000. *Bull Bars and Road Trauma*, CR200, Department of Transport and Regional Services, Australian Transport Safety Bureau.

[2] P. Rowden, D. Steinhardt and M. Sheehan. 2008. Road crashes involving animals in Australia, *J. Accident Analysis & Prevention*, 40, 1865-1871. http://dx.doi.org/10.1016/j.aap.2008.08.002.

[3] I.V. Lau, J.D. Horsch, D.A. Viano and D.V. Andrzejak. 1993. Mechanisms of injury from air bag deployment loads, *J. Accident Analysis & Prevention*, 25, 29-45. http://dx.doi.org/10.1016/0001-4575(93)90094-D.

[4] N.M. Thota, J.A. Eepaarachchi and K.T. Lau. 2013. Effect of the foam embellishments on the pedestrian safety of the vehicle front protection systems, *Int. J. Engg. Research and Tech.*, 6, 11-14.

[5] R.W.G. Anderson, S.D. Doecke, A.L.V.D. Berg, D.J. Searson and G. Ponte. 2009. *The Effect of Bull Bars on Head Impact Kinematics in Pedestrian Crashes*, Centre for Automotive Safety Research, The University of Adelaide, Australia.

[6] R.W.G. Anderson, G. Ponte and S.D. Doecke. 2008. *A Survey of Bullbar Prevalence at Pedestrian Crash Sites in Adelaide, South Australia*, Centre for Automotive Safety Research, The University of Adelaide, Australia.

[7] S.D. Doecke, R.W.G. Anderson and G. Ponte. 2008. Bull bar prevalence among types of vehicle in metropolitan Adelaide, *Proc. Australasian Road Safety Research, Policing and Education Conf.*, Adelaide, Australia.

[8] H. Chiam and J. Tomas. 1980. Investigation of the effect of bull-bars on vehicle-pedestrian collision dynamics, CR13, Department of Transport and Regional Services, Australian Transport Safety Bureau.

[9] B. Hardy. 1996. *A Study of Accidents Involving Bull Bar Equipped Vehicles*, TRL243, Transport Research Laboratory, UK.

[10] G. Lawrence and B. Hardy. 1992. *Vehicle Crash Bars-Assessment of Pedestrian Injury Potential*, TRL Working Paper, WP/VS/225, Transport Research Laboratory, UK.

[11] Australian Standard 4876.1.2002, *Motor Vehicle Frontal Protection Systems, Part 1: Road User Protection*.

[12] P. Bignell. 2004. *Evaluation of the performance and Testing Techniques of Vehicle Frontal Protection Systems*, PhD Thesis, Queensland University of Tech., Australia.

[13] B. Sredojevic and G. Zivkovic. 1998. *Vehicle front protection systems (Bull Bars): Airbag Compatibility Tests*, Automotive Safety Engineering Pty Ltd, Australia.

[14] J.T. Correia, K.A. Iliadis, E.S. McCarron, M.A. Smolej, B. Hastings and C.C. Engineers. 2001. Utilizing data from automotive event data recorders, *Proc. Canadian Multidisciplinary Road Safety Conf XII, London, Ontario*.

[15] A. Chidester, J. Hinch and T.A. Roston. 2001. Real world experience with event data recorders, *Proc. 17th Int. Technical Conf. Enhanced Safety of Vehicles,* Amsterdam, Netherlands.

[16] M. Ueyama, S. Ogawa, H. Chikasue, and K. Muramatu. 1998. Relationship between driving behaviour and traffic accidents-accident data recorder and driving monitor recorder, *Proc. 16th Int. Technical Conf. Enhanced Safety of Vehicles*, Washington, USA.

[17] C.Y. Chan. 2002. On the detection of vehicular crashes - System characteristics and architecture, *IEEE Trans. Vehicular Tech.*, 51, 180-193. http://dx.doi.org/10.1109/25.992078.

[18] C.Y. Chan. 2002. A treatise on crash sensing for automotive air bag systems, *IEEE/ASME Trans. Mechatronics*, 7, 220-234. http://dx.doi.org/10.1109/TMECH.2002.1011259.

[19] C.Y. Chan. 2000. *Fundamentals of Crash Sensing in Automotive Airbag Systems*, Society of Automotive Engineers. http://dx.doi.org/10.4271/R-217.

[20] A. Morris, J. Barnes, B. Fildes, F. Bentivegna and K. Seyer. 2001. *Effectiveness of ADR 69: A Case-Control Study of Crashed Vehicles Equipped With Airbags*. Australian Transport Safety Bureau - Contract Report No. 199, Monash Injury Research Institute, Monash University, Australia.

[21] W.T. Hollowell, H.C. Gabler, S.L. Stucki, S. Summers and J. Hackney. 1999. *Updated Review of Potential Test Procedures for FMVSS*, Report No. 208, NHTSA Office of Vehicle Safety Research.

[22] P.J. Schuster. 2006. Current trends in bumper design for pedestrian impact, *Proc. SAE World Congress,* Detroit, Michigan.