ENHANCED VEHICLE COLLISION COMPATIBILITY – PROGRESS REPORT OF US TECHNICAL WORKGROUP FOR FRONT-TO-FRONT COMPATIBILITY

Mukul K. Verma
EVC Technical Workgroup for Front-to-Front Compatibility
USA
Paper number 07-0291

ABSTRACT

This paper presents estimates of benefits resulting from the voluntary agreement by the motor vehicle manufacturers in the USA for enhancing compatibility in front-to-front collisions between light truck based vehicles and passenger cars. Two studies of accident data and one study based on crash tests are reported herein.

In addition, the members of the technical workgroup are researching methods to measure and predict the structural interaction of vehicles in crashes and to quantify their relative structural strength levels. Ongoing work on three parallel paths of research for improving vehicle compatibility is described in this paper - (a) full-width fixed deformable barrier with load cell wall approach; (b) CAE-based evaluations of vehicle to vehicle impacts; and (c) development of car surrogate mobile deformable barrier as a test device.

INTRODUCTION

The Enhanced Vehicle Compatibility (EVC) technical workgroup was created in order to develop solutions for improving crash compatibility between passenger cars and light truck based vehicles (LTVs). Organized initially by the Alliance of Automobile Manufacturers, this workgroup now has members from automakers (BMW Group, DaimlerChrysler Corporation, Ford Motor Company, General Motors, Honda, Hyundai Motor, Isuzu Motors, Kia Motors, Mazda, Mitsubishi Motors, Nissan, Subaru, Suzuki, Toyota and Volkswagen) as well as from the Insurance Institute for Highway Safety, Transport Canada, and Transport Research Laboratory (UK). Studies conducted by members of this workgroup have led to recommendations for primary and secondary energy absorbing structures for LTVs to improve collision compatibility in frontal crashes with cars [1]. These recommendations include criteria for increased geometric overlap of these structures with the zone specified for passenger car energy absorbing structures as well as criteria for minimum structural strength of secondary energy absorbing structures. These have been voluntarily accepted as performance criteria by almost all manufacturers for LTVs sold in the USA. This paper presents estimates of potential benefits in collision compatibility that may result from the workgroup's recommendations and summarizes the status of research activities of this workgroup.

ESTIMATED BENEFITS FROM WORKGROUP RECOMMENDATIONS

Three studies have been completed for estimating the effect of the previous recommendations made by this workgroup regarding light truck vehicles (LTV).

IIHS Study

A study was conducted [2] to estimate the benefits that may occur from SUVs and pickup trucks conforming to this workgroup's recommendations. This was done by looking at passenger car driver deaths in two-vehicle collisions where the car was struck by a pickup truck or an SUV. FARS data from years 2001 to 2004 for car-to-SUV and car-to-pickup truck collisions were studied and comparisons were made between SUVs and pickups that conform to the recommendations to those that did not conform to these guidelines. Only SUVs and pickup trucks of model years 2000 through 2003 were included in the study for both front-to-front as well as front-to-side collisions (where the front end of a light truck strikes the driver side of a passenger car).

The vehicles were divided into 500 lb groups. The fatality rate for each group was obtained by dividing the number of car driver fatalities by the number of vehicle registrations reported by R. L. Polk for SUVs and pickup trucks in that specific group. The resulting rate is the number of fatalities in the struck car per million striking vehicle registered-vehicle-years. These weight group rates are then combined to calculate overall estimated benefits for SUVs and for pickup trucks in each of the two collision configurations.

In front-to-front collisions with SUVs, conforming vehicles had a 16% reduction in estimated risk of fatalities whereas conforming pickups had a 20%

Overall Estimated Fatality Risk Reduction		
Crash type	**Vehicle type**	**Risk Reduction**
Front-to-front	**SUVs**	**16%**
	Pickups	**20%**
Front-to-driver side	**SUVs**	**30%**
	Pickups	**10%**

Table 1: Estimated Benefits in Compatibility

reduction. In front-to-side impacts, a 30% risk reduction for SUVs and a 10% risk reduction for pickups were observed.

Ford Study

The effect of adding SEAS to LTVs (one of the recommendations of this workgroup) was evaluated by comparing collision data for LTVs with SEAS to that for similar vehicles without SEAS and is presented separately [5].

GM Study

In this study, the effect of adding a secondary energy absorbing structure to an LTV was measured in controlled, full-overlap frontal crash tests with a passenger car (Figure 1). In each case, a stationary LTV was impacted by a passenger car moving at 58 mph to obtain the intended ΔV of 35 mph in the struck car. In these tests, SEAS designed in accordance with the ‘option 2’ criteria was added to a baseline LTV whose PEAS structure did not have the amount of overlap with Part 581 zone necessary for conformance with the ‘option 1’ criteria [1].

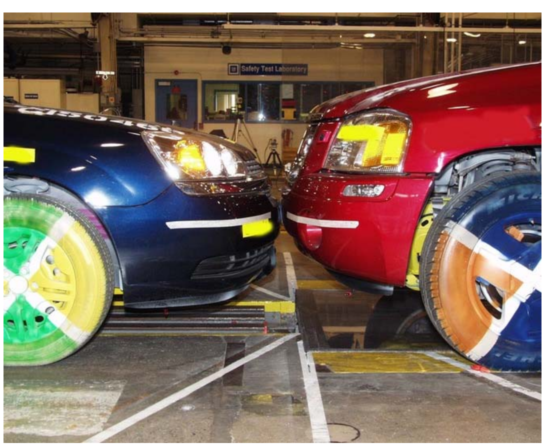


Figure 1: Pre-Impact Setup for Car versus LTV Tests

Some of the results from these tests are shown in Figures 2 and 3. Figure 2 shows the measured passenger car intrusions from impact with the baseline LTV compared to those from impact with the modified LTV. It is observed that the effect of added SEAS is a significant decrease in almost all the intrusion values measured in the car.

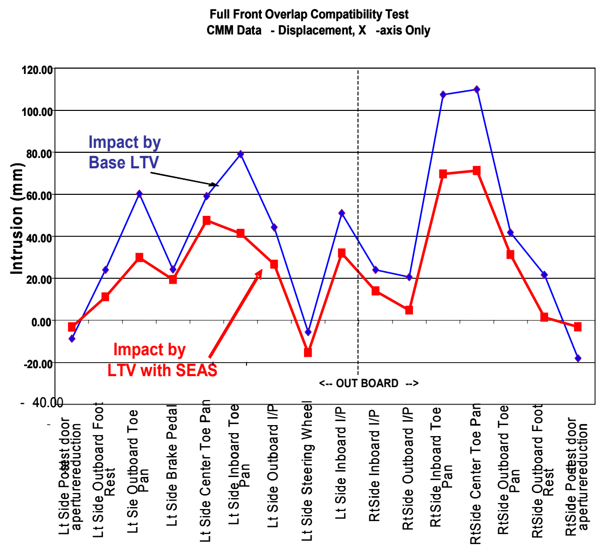


Figure 2: Measured Intrusions in Car-to- LTV Impacts – Effect of SEAS

Figure 3 below shows the response of a 50th percentile Hybrid III anthropomorphic test device (ATD) in the car driver seat in impact with the baseline and modified LTVs. Again, the effect of the added SEAS is observed to be an improvement in the car occupant protection as measured by ATD response.

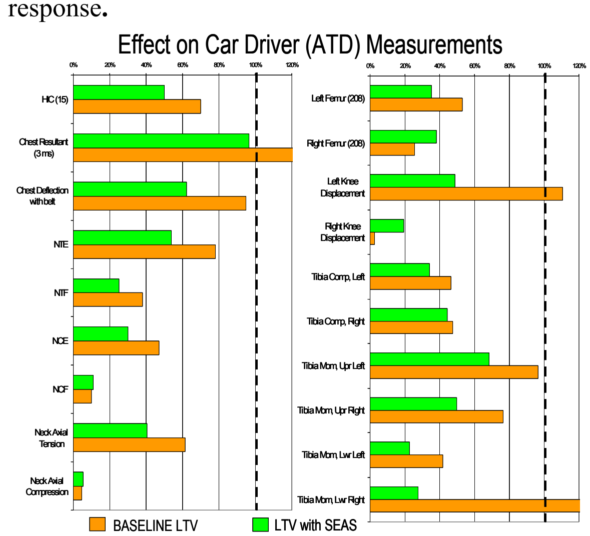


Figure 3: Measured Response of Car Driver ATD in Car-to-LTV Impacts – Effect of SEAS in LTV

CURRENT RESEARCH ACTIVITIES OF WORKGROUP

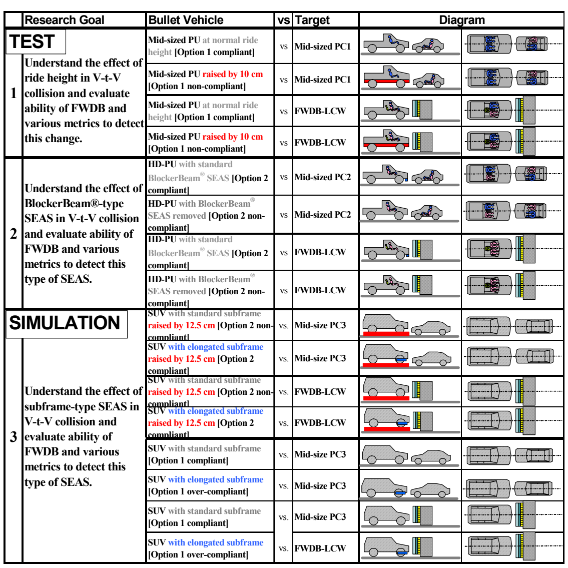
From the above studies, it is evident that the workgroup's recommendations will provide significant benefits in collision compatibility as they are implemented in the design of LTVs. However, research continues by the workgroup members for developing additional recommendations leading to further improvements in collision compatibility in front-to-front impacts [3].

This workgroup's charter is to develop compatibility improvement proposals for LTVs that do not cause significant reductions in the self-protection in these vehicles. Currently, there are three distinct research paths being pursued by this workgroup and these are described below.

1. Fixed Barrier Load Cell Wall (LCW) Approach

The aim of this research path is to develop a dynamic test procedure using a full-width deformable barrier (FWDB) load cell wall (LCW) and load-based metrics to quantitatively evaluate the collision compatibility of LTVs.

Three series of studies (Figure 4) have been performed.



	Research Goal	Bullet Vehicle	vs	Target	Diagram
TEST					
1	Understand the effect of ride height in V-t-V collision and evaluate ability of FWDB and various metrics to detect this change.	Mid-sized PU at normal ride height [Option 1 compliant]	vs	Mid-sized PC1	
		Mid-sized PU raised by 10 cm [Option 1 non-compliant]	vs	Mid-sized PC1	
		Mid-sized PU at normal ride height [Option 1 compliant]	vs	FWDB-LCW	
		Mid-sized PU raised by 10 cm [Option 1 non-compliant]	vs	FWDB-LCW	
2	Understand the effect of BlockerBeam®-type SEAS in V-t-V collision and evaluate ability of FWDB and various metrics to detect this type of SEAS.	HD-PU with standard BlockerBeam® SEAS [Option 2 compliant]	vs	Mid-sized PC2	
		HD-PU with BlockerBeam® SEAS removed [Option 2 non-compliant]	vs	Mid-sized PC2	
		HD-PU with standard BlockerBeam® SEAS [Option 2 compliant]	vs	FWDB-LCW	
		HD-PU with BlockerBeam® SEAS removed [Option 2 non-compliant]	vs	FWDB-LCW	
SIMULATION					
3	Understand the effect of subframe-type SEAS in V-t-V collision and evaluate ability of FWDB and various metrics to detect this type of SEAS.	SUV with standard subframe raised by 12.5 cm [Option 2 non-compliant]	vs.	Mid-size PC3	
		SUV with elongated subframe raised by 12.5 cm [Option 2 compliant]	vs.	Mid-size PC3	
		SUV with standard subframe raised by 12.5 cm [Option 2 non-compliant]	vs.	FWDB-LCW	
		SUV with elongated subframe raised by 12.5 cm [Option 2 compliant]	vs.	FWDB-LCW	
		SUV with standard subframe [Option 1 compliant]	vs.	Mid-size PC3	
		SUV with elongated subframe [Option 1 over-compliant]	vs.	Mid-size PC3	
		SUV with standard subframe [Option 1 compliant]	vs.	Mid-size PC3	
		SUV with elongated subframe [Option 1 over-compliant]	vs.	FWDB-LCW	

Figure 4: FWDB related test and simulation series.

Test Series 1 – Height of PEAS

The baseline pickup truck has PEAS whose height conforms to 'option 1' criteria [1] and the modified truck's ride height was increased from this by 10 cm. In the truck versus car tests (Figure 5), it was observed that the PEAS of the baseline truck overlapped that of the car by a significant amount but there was no overlap when the truck was raised. Also,

Figure 5: Pre-test alignment of baseline (left) and raised pickup (right) with car.

the raised truck's PEAS height did not conform to the 'option 1' [1]. Shown in Figure 6 are the interactions between the vehicles in each case.

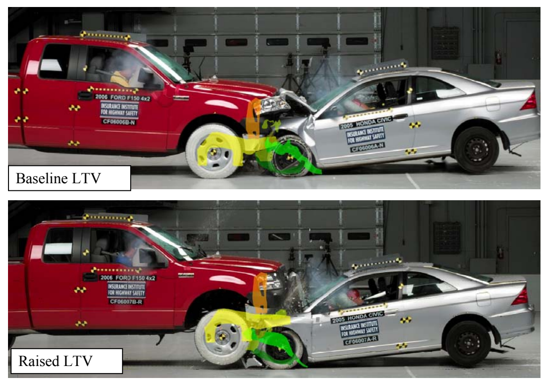


Figure 6: LTV vs Car tests for baseline LTV (top) and for raised LTV

Examination of the test film showed structural engagement between the truck and the car in the test with the baseline truck whereas in the test with the raised truck, it was observed that the truck's wheels lifted off ground during the test.

Figure 7 shows measured intrusions in the passenger car in each test. The intrusions in the car were low in both the cases even though the structural engagement

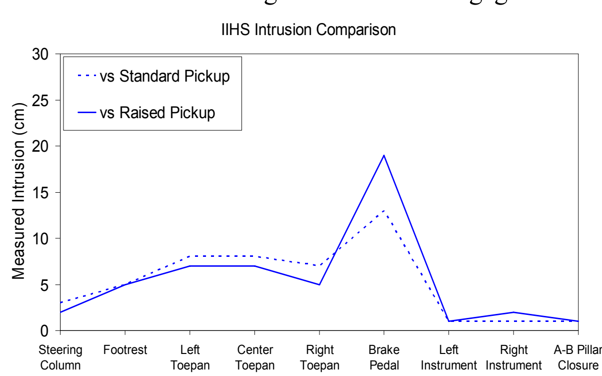


Figure 7: Car Compartment Intrusion

with the truck was different in the two tests. Raising the height of the truck appears to have the effect of reduced intrusions at all points except at the brake pedal which showed an increase.

Figure 8 shows the measured decelerations in the car in impacts with the baseline truck and with the raised truck. The effect of raising the truck is observed to be lower deceleration in the car earlier in the impact but an increase in the peak value later in the impact.

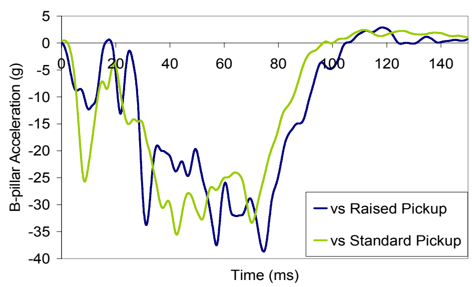


Figure 8: Car Deceleration vs Time Results

The resulting response of the 50th percentile Hybrid III ATD on the driver side in the car is shown in Figure 9. Relatively lower deceleration levels earlier in the event with the raised LTV caused delayed front airbag deployment in the car and this may be a factor in the observed ATD response. The ATD injury criteria were all below the standard regulatory limits (except for the tibia index) although the values were generally higher for the test against the raised truck.

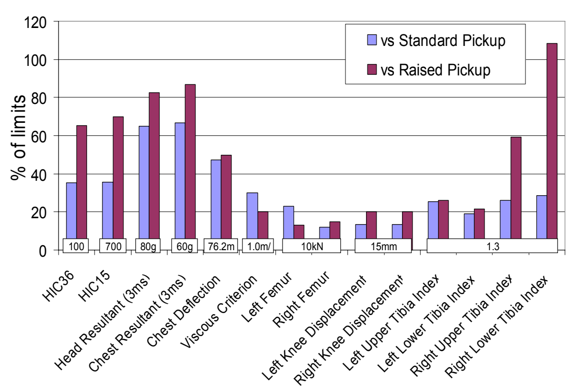


Figure 9: ATD Responses in Car to LTV Impact

Results from FWDB impact of the baseline truck and the raised truck indicate that the raised truck applies lower load in row 3 and higher load in row 4 than the baseline truck (rows 3 and 4 are the rows in alignment with the top and bottom of the CFR49 Part 581 zone, respectively). The sum of the peak cell loads is shown in Table 2 where 'metric 1' is the summation of peak values of measured loads independent of time and 'metric 2' is the value when the results are truncated to 40 milliseconds.

Truck	Metric 1 Sum peak cell loads (kN)		Metric 2 Sum peak cell loads up to 40 ms (kN)	
	Row 3	Row 4	Row 3	Row 4
Baseline	279	328	205	321
Raised	94	447	45	397

Table 2: Comparison of Peak Cell Loads on Rows 3 & 4 for Baseline Truck and Raised Truck

These values should be compared to an example value of 100 kN.

A comparison of the AHOF (Figure 10) shows that AHOF does not define the location of the PEAS of the vehicle but may be able to show the change in height although with a significant (20%) error.

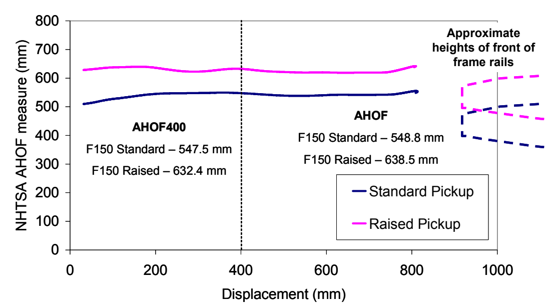


Figure 10: Comparison of AHOF versus B-pillar Displacement for Baseline and Raised Trucks.

In conclusion, the results of this test series show that the alignment of this LTV's PEAS with the CFR49 Part 581 zone increased its structural interaction with the test car and reduced most of the injury measures on ATD in the car. Also, FWDB results show that metrics based on peak cell loads on rows 3 and 4 can detect a large (> 10 cm) change in height of PEAS of the LTV. AHOF also appears to provide this discrimination but it is not an indicator of the position of the vehicle structure.

Test Series 2 – BlockerBeam® type SEAS

The capability of FWDB metrics to detect removal of SEAS in a full size pickup truck was investigated and detailed results from this test series are reported in a separate publication [5].

Simulation Series – Sub-frame type SEAS

Finite element models of an LTV and a car were used to study the effect of adding sub-frame type SEAS to the LTV. Two simulations were conducted with raised SUVs - one being an SUV with a sub-frame type SEAS and the other one without SEAS. Both the vehicles were raised in the simulation by125 mm over the standard height so that the vehicle with SEAS conformed to the 'option 2' criteria [1] and the vehicle without SEAS did not conform. In the SUV–versus-car simulations, the front end structure of the car (Figure 11, 12) shows significant overlap with the

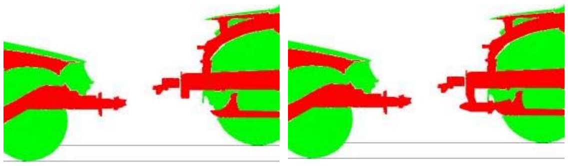


Figure 11: Alignment of Raised (left) SUV and Raised SUV with sub-frame SEAS versus Car.

with that of the sub-frame SEAS, but not so for the SUV without the added SEAS.

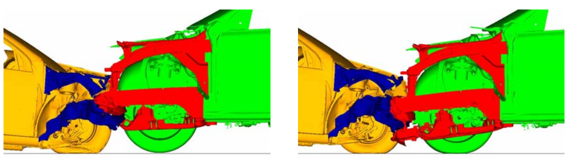


Figure 12: SUV vs Car Simulation at 75 msec – Increased structural interaction for Raised SUV with sub-frame SEAS (right)

The cars' compartment intrusions in the simulated impact (Figure 13) were very low (all but one <50 mm) in both studies, the raised SUV with sub-frame SEAS causing approximately 14% less intrusion in the car than the raised SUV without the SEAS.

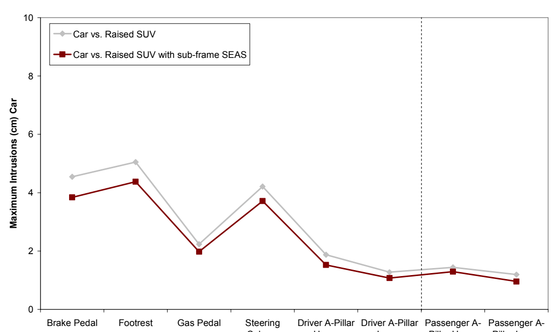


Figure 13: Car compartment intrusion in LTV Impacts

The Load Cell Wall (LCW) results for both SUVs are shown in Table 3. The addition of the sub-frame SEAS adds significantly to the loading of row 3 and row 4. In both cases, row 4 loads exceeded 100 kN.

Vehicle	Metric 1 Sum peak cell loads (kN)		Metric 2 Sum peak cell loads up to 40 ms (kN)	
	Row 3	Row 4	Row 3	Row 4
Raised SUV	75	154	38	130
Raised SUV with sub-frame SEAS	237	248	135	150

Table 3: Loads on rows 3 and 4 for Raised SUV with and without sub-frame SEAS.

A plot of the average height of force (AHOF) against B-pillar displacement (Figure 14) shows a change in AHOF between two vehicles. Similar simulation studies were also conducted for SUVs at the standard

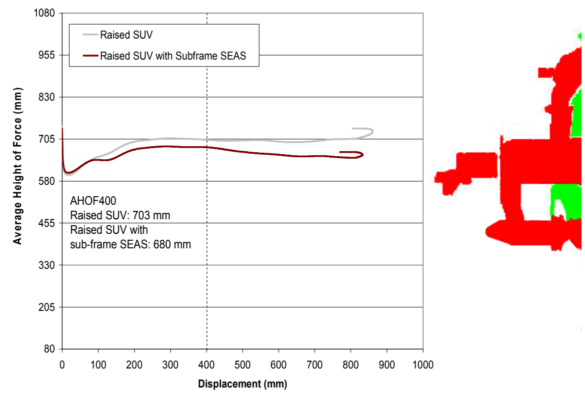


Figure 14: AHOF versus B-pillar Displacement for Raised SUV with and without sub-frame SEAS

ride height. In these studies, intrusions in car were low in impact by either SUV; however the addition of the sub-frame increased the intrusions by an average of 51%. Similar results were also seen in the car's peak and average decelerations where the SUV with sub-frame SEAS causes higher values. A comparison of the metric 1 and 2 row loads shows that both configurations of the standard SUVs meet the 100kN requirement for both row 3 and row 4. Hence these metrics would not encourage the addition of SEAS to the baseline SUV. The AHOF value was lowered by the addition of the SEAS.

In summary, the results of the FWDB simulations show that metrics 1 and 2 can detect the presence of sub-frame type SEAS for this case of raised SUVs, although the minimum row load of 100 kN was met with or without SEAS. The AHOF value shows that addition of SEAS lowers the calculated AHOF in this case. Another observation from this study is that the addition of SEAS to the raised SUV resulted in lower intrusions in the car but for the standard height SUV, addition of SEAS indicated increased intrusions which may indicate the need for integrating SEAS design with the overall front end design.

2. CAE- Based Approach

This research path is intended to develop a procedure for using finite element models of vehicles for compatibility evaluations. The planned tasks are
- Evaluation of LTVs in simulated impacts with finite element model of a 'representative car';
- Results to be synthesized into 'compatibility metric';

With this approach, it may be possible to evaluate collision compatibility in multiple impact configurations. The availability of appropriate finite element models of vehicles and the protocol for sharing such data is being currently discussed in the workgroup.

3. Development of Car Surrogate MDB for LTV Impacts

This approach is based on the assumption that 'improved collision compatibility' between a large vehicle and a smaller one implies 'improved protection of occupants in the smaller vehicle'. This of course needs to be achieved without any significant degradation in self-protection of either vehicle. Thus, an objective measure of improvement of occupants' safety in the smaller vehicles (when impacted by a larger vehicle) is a suitable measure of improved compatibility of the larger vehicle.

The intent of this research is to develop a moveable deformable barrier (MDB) that is a surrogate of a representative car for the purpose above. Thus, one of the challenges of the study was to select the 'US fleet representative' car in a 'field-representative' impact configuration [5]. The values selected for this are as follows [6]:
- Car mass of 1600-1700 kg,
- Full frontal impact with LTV as first priority,
- ΔV of 35 mph in struck car, representing 97th percentile in LTV to car crashes.

The car-surrogate MDB is developed to be representative of the car in front crush and in deceleration levels. In order to evaluate the degree of surrogacy achieved, it is necessary to compare these crush and deceleration levels in the reference car to those obtained using the MDB in impacts with LTVs. Since test results are subject to variations, it was necessary to determine the range of responses that may be achieved in nominally identical (but subject to test variations and build variations) LTV to car impacts and to define the MDB to represent this range. The range of responses in the vehicles selected is shown in Figure 15.

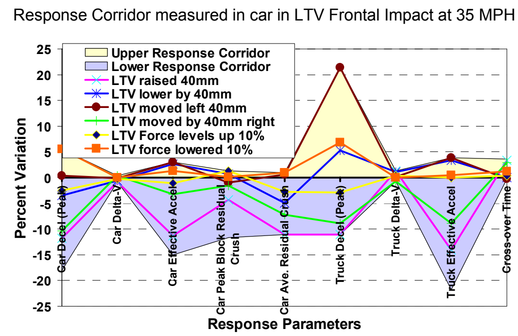


Figure 15: Response Corridor of Car in Impacts with LTV

An MDB configuration has been developed [6] using finite element simulations of the car and the LTVs. This MDB (Figure 16) consists of aluminum plates and blocks of honeycomb material of various densities and strengths to approximate the components in the front end of the vehicle.

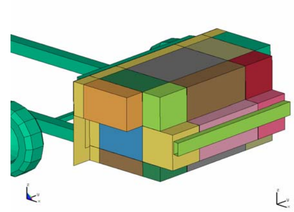


Figure 16 - Schematic of Car-surrogate MDB

The response of the proposed MDB as compared to the response corridor of car is shown in Figure 17.

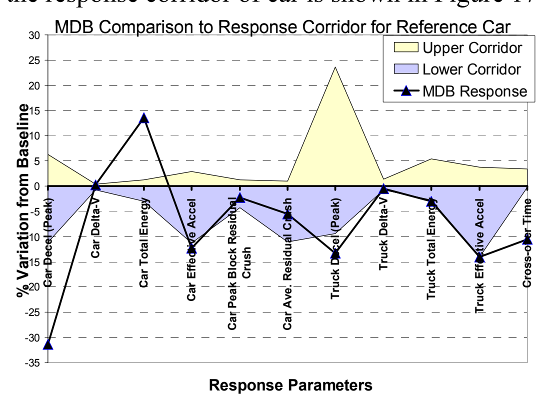


Figure 17: Comparison of MDB to Car Response Corridor

Physical prototypes of the MDB have been built and the MDB has been evaluated in component level tests (Figure 18). Based on the results from such

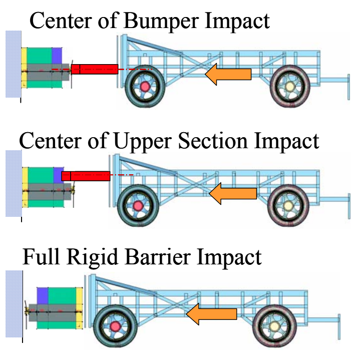


Figure 18: Component Test Configurations for Car Surrogate MDB Evaluation

tests (e.g. deformations in one test shown in Figure 19), several modifications have been made in the original configuration. The modified MDB is being fabricated and MDB-to-LTV tests and comparative evaluations with car-to-LTV tests have been planned.

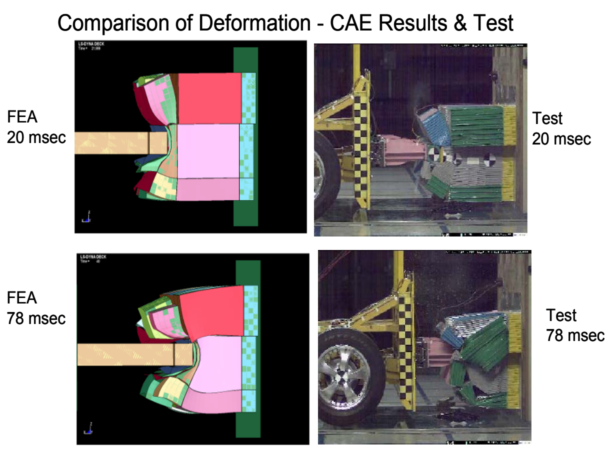


Figure 19: Comparison of Test Results from Centre of Bumper Impact to CAE results

ACKNOWLEDGEMENTS

This paper is a summary of contributions by many members of the workgroup. Special thanks are due to Mervyn Edwards of Transportation Research Laboratory, Sean O'Brian of Volkswagen and Alex Genetos of the Insurance Institute for Highway Safety for providing much of the written material.

REFERENCES

1. Barbat, S., (2005). 'Status of Enhanced Front-To-Front Vehicle Compatibility Technical Working Group Research and Commitments', 19th ESV, Washington, DC 2005, Paper No 05-463.

2. Baker, B., Nolan, J., O'Neill, B., Genetos, A., 'Crash Compatibility between Cars and Light Trucks: Benefits of Lowering Front-End Energy-Absorbing Structure in SUVs and Pickups', Insurance Institute for Highway Safety, Arlington, VA, 2007.

3. Verma, M., "Progress in Vehicle Collision Compatibility Improvements – A Report from EVC Technical Group", Presented at Final Workshop VC-COMPAT Project, Eindhoven, October 2006. http://vc-compat.rtdproject.net/,

4. Edwards et al. (2007). 'Current Status of the Full Width Deformable Barrier Test', Paper No. 07-0088, 20th ESV Conference, Lyon, France 2007.

5. Barbat, S., 'Vehicle Compatibility Assessment Using Test Data of Full Frontal Vehicle-to-Vehicle and Vehicle-to-Full Width Deformable Barrier Impacts', Paper number 07-0348, 20th ESV Conference, Lyon, France 2007.

6. Peddi, S., Subramanaim K., Sharma V., Verma M., Schuyten H., 'Development of a Mobile Deformable Barrier as Car Surrogate', Paper no. 2007-01-1179, SAE Annual Congress, 2007.