The Effect of Reduced Mass on Frontal Crashworthiness

Fadi J. Tahan, Chung-Kyu Park, Richard M. Morgan, Chongzhen Cui, Bavneet Brar, Kurt Shanks, Cing-Dao Kan

Abstract The objective of this study is to investigate the frontal crashworthiness effects of reducing the mass of a mid-size car, while maintaining its stiffness and size. Non-structural components of the vehicle were selected and four light-weight vehicle models were generated by reducing the mass by 10%, 20%, 30% and 40%. Mathematical optimization was used to maintain the CG location. To compare the crashworthiness of the four light-weight cars to the original mid-size car, all cars were crashed using LS-DYNA finite element (FE) simulations in (1) New Car Assessment Program frontal (NCAP), (2) Insurance Institute for Highway Safety frontal offset (IIHS), (3) car-to-car frontal at 40% and 100% overlaps, and (4) pick-up truck-to-car (Silverado) at 40% and 100% overlaps frontal crashes. For vehicle-to-vehicle frontal crashes, the acceleration increased and occurred sooner as compared to the original car pulse while for the other test configurations the acceleration peaks were comparable. For all frontal crashes, the acceleration peaked earlier as compared to the original mid-size car pulse. Regarding occupant compartment intrusion, the residual intrusions decreased with the mid-size model mass reduction except for the mid-size vehicle struck by pick-up truck at 100% overlap.

Keywords Crashworthiness, frontal vehicle crash, finite element simulation, light weight, mass reduction.

I. INTRODUCTION

Vehicle mass is an important subject in crashworthiness safety. All future vehicles likely will be subjected to mass reduction to meet the new fuel-efficiency requirements. The compatibility between these lighter vehicles and the heavier, old fleet is a safety concern. Any change in vehicle size is also a concern.

Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA) regulations will increase fuel economy to the equivalent of 54.5 mpg for cars and light-duty trucks by Model Year 2025 [1]. The new regulation will drive the automotive industry to reduce vehicle mass through advancements in materials. Kamiji [2] noted that for the Honda Accord model years (MYs) 1994, 1998, 2003 and 2008, the percentage of high strength steel increased from zero to 48% of all steel used in the vehicle. For the present time frame out to 2015, Honda is reducing weight by (1) optimizing the structure, (2) revising joint connection methods and (3) increasing the use of high strength steel.

While vehicle mass may affect occupant safety in collisions, vehicle size is also a factor in the risk of fatalities. Kahane [3] studied the relationship between fatality rate, mass and vehicle footprint for real-world crash data for eight State Data Files. He defined footprint as equal to track width times the wheelbase for a vehicle. Kahane found that the fatality increase per 100-pound mass reduction (holding footprint constant) was 2.21% for cars < 2,950 pounds. For cars ≥ 2,950 pounds, the fatality rate increase was 0.9%. For light trucks and vans (LTVs) < 3,870 pounds, the increase was 0.17%. The fatality rate decreased 1.9% for LTVs ≥ 3,870 pounds. If mass reduction in the MY 2012 – 2016 fleet emphasizes the heavier LTVs and maintains vehicle footprints, the fatality rate would not be expected to increase significantly.

Additionally, Evans [4]–[5] noted that real-world crash analysis firmly establishes that the heavier a vehicle is,

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the more protection it offers to the driver in a car-to-car collision. However, two significant downsides are associated with heavier vehicles: (1) a heavier vehicle increases risk to the occupants of the other vehicle and (2) a heavier vehicle burns more fuel. Evans suggests that the key to making a lighter car safer is to recognize that the size, or length, of the vehicle also affects safety. For equal mass vehicles, a larger vehicle reduces risk to its occupants.

II. METHODS

In this research, light-weight vehicles are developed by reducing the mass of the mid-size passenger car in order to investigate the mass reduction effects on vehicle crashworthiness. Vehicle mass reduction can be attained in several ways, but the objective of this paper is not to investigate mass reduction methods and material selections. In this research, the mass reduction strategy is based on leaving 2 factors unchanged: vehicle dynamics and vehicle frontal structural stiffness.

From a vehicle dynamics perspective, it is essential to keep the vehicle front-to-rear weight ratio the same. Once the vehicle mass distribution is maintained, the vehicle inertias are similar to the original model. This factor is essential to preserve the vehicle performance in the redesigned model. Therefore, the center of gravity (CG) of the reduced mass models should be within an acceptable tolerance of the original model in the longitudinal, lateral and vertical directions.

Additionally, the vehicle crashworthiness performance is an important aspect of vehicle safety design. Several sub-systems contribute to this factor. Since a specific vehicle model uses a platform that undergoes minor structural changes over the years, this study maintains the vehicle structure strength load-bearing portion while reducing mass in other parts of the vehicle. The design approach was to keep the structural stiffness intact, and did not look at how to achieve the mass reduction targets from a manufacturing or cost perspective.

Based on the above 2 constraints (vehicle dynamics and vehicle crashworthiness), the mass reduction analysis is based on numerically changing the density of components that are non-influential on vehicle stiffness. This strategy is defined as the non-structural components mass reduction. The values (percentage) of mass reduction to be attempted are 10%, 20%, 30% and 40% from the original model mass. The following 2 sections, mass reduction approach and mathematical optimization, describe the steps performed in order to generate the different mass reduction models.

Non-structural Mass Reduction Model Approach

The vehicle components were divided into 2 groups: structural and non-structural components. The distinction of these two groups is a key factor to meet the crashworthiness conditions specified in the strategy. The structural components include the chassis, body structure and closures, and key components of the crushing portion of the mid-size car during an accident. The non-structural components include the power train, interior, and any other systems that do not play a role in the vehicle crashworthiness. Figure 1 shows the non-structural components. Based on the mass reduction strategy selected, the structural components were not included in any mass reduction alteration. The non-structural components were limited to parts that weigh more than 0.1 kg. Over 200 different components were identified and these components had their density changed in order to reduce the vehicle mass.

Mathematical Optimization

To satisfy the vehicle dynamic condition of the original mid-size vehicle, the mass distribution of the vehicle should be maintained. The mass distribution is governed by equations 1 to 3.

$$\Sigma m^{i} \times x^{i} = \Sigma M^{mid-size} \times X^{CG}, \quad (1)$$

$$\Sigma m^{i} \times y^{i} = \Sigma M^{mid-size} \times Y^{CG}, \quad (2)$$

$$\Sigma m^{i} \times z^{i} = \Sigma M^{mid-size} \times Z^{CG}, \quad (3)$$

where m^i is the mass of each component and M is the mid-size car total mass,

x^i is the x-coordinate of the CG for each component, and X^{CG} is the x-coordinate of the mid-size car CG,

y^i is the y-coordinate of the CG for each component, and Y^{CG} is the y-coordinate of the mid-size car CG, and

z^i is the z-coordinate of the CG for each component, and Z^{CG} is the z-coordinate of the mid-size car CG.

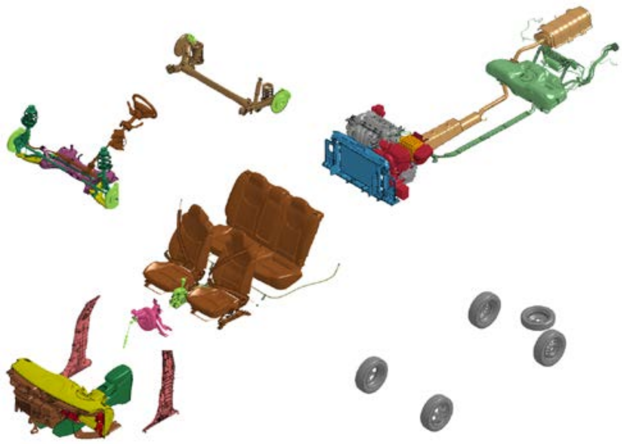


Fig. 1. Vehicle non-structural components

The model was divided into 2 groups. The first group contained the structural components and the second group contained the selected non-structural components. The optimization software CONMIN [6] was used with the governing equations that verify the vehicle dynamic conditions. The goal of the software is to calculate the optimum non-structural components mass (m^i) while maintaining the equality of the equations within an allowable margin of error. The mass of the structural component group was kept constant as a constraint for the optimization process in order to keep intact the original crashworthiness design of the mid-size car.

The program was adjusted to include the equations, the constraints and the target mass reduction values of 10%, 20%, 30% and 40% of the baseline model. The constraint was to minimize the CG location position to no more than 10 mm variation from the original baseline model. The optimization program output different density scaling values. The non-structural group of components maintained the original stiffness and thickness, but the density in the finite element (FE) model was reduced by the scale factor calculated by CONMIN. Once the models were generated, they were run using LS-DYNA [7] and the center of gravity location was verified to meet the allowable tolerance specified earlier (10 mm in each direction) [8]. Table 1 shows the original and the reduced mass models for the 4 different target models. The actual mass values calculated from LS-DYNA show that the percent reduction was satisfactory. The variation of the 40% mid-size mass reduced (MSMR) model is slightly low with a 2.82% lower mass relative to the target value.

TABLE I

ACTUAL MASS REDUCTION MODELS PROPERTIES

	Original (Baseline) Model	Mass Reduced (Target) Models			
	0%	10%	20%	30%	40%
Actual Vehicle Mass (kg)	1244.502	1118.847	1003.702	875.035	781.765
Actual Mass Reduction	0.00%	10.10%	19.35%	29.69%	37.18%

To assess the safety of the reduced mass designs, several frontal impact configurations were addressed in this study. The New Car Assessment Program (NCAP), the Insurance Institute for Highway Safety (IIHS) [9] offset deformable barrier [10], mid-size car to mid-size car with 100% overlap, pick-up truck (Silverado) [11] to mid-size car with 100% overlap, mid-size car to mid-size car with 40% overlap, and pick-up truck (Silverado) to mid-size car with 40% overlap crash tests were performed. A total of 30 full-scale simulations were performed.

All models had an additional mass of 180 kg to represent driver and passenger dummies and the measurement devices used in the NCAP test. The masses (77 kg Hybrid III 50th percentile male dummy, 50 kg Hybrid III 5th percentile female dummy and 53 kg measurement devices) were attached to the driver and passenger seat structures and to the trunk panel.

III. RESULTS

The baseline mid-size car and the mid-size mass reduced (MSMR) models were simulated following NCAP test configurations. The test speed for the simulations was 56 km/h (35 mph). Detailed results are shown in Figure 2. The cross-section cut plane of the baseline model and the MSMR structural models passing through the steering wheel of up to 70 milliseconds of simulation time are shown in the left hand side of Figure 2. The average x-acceleration from the right and left rear seat accelerometers for all the models and the force-displacement curves are shown in the top and bottom right graphics of Figure 2, respectively. At different simulation times, the acceleration and load progression is tracked on the curves by a square curser for each model.

The maximum accelerations for the lighter vehicles are lower than the baseline maximum acceleration (less than 3 G's). However, the acceleration of the lower mass vehicles occurs sooner. The average x-velocity time to zero is reduced by 7 milliseconds when the vehicle is reduced by 40% of its original mass from the original model. The driver floor panel intrusion measured is shown in Figure 3. These intrusions suggest that the lighter MSMR vehicles have less compartment intrusion than the baseline vehicle.

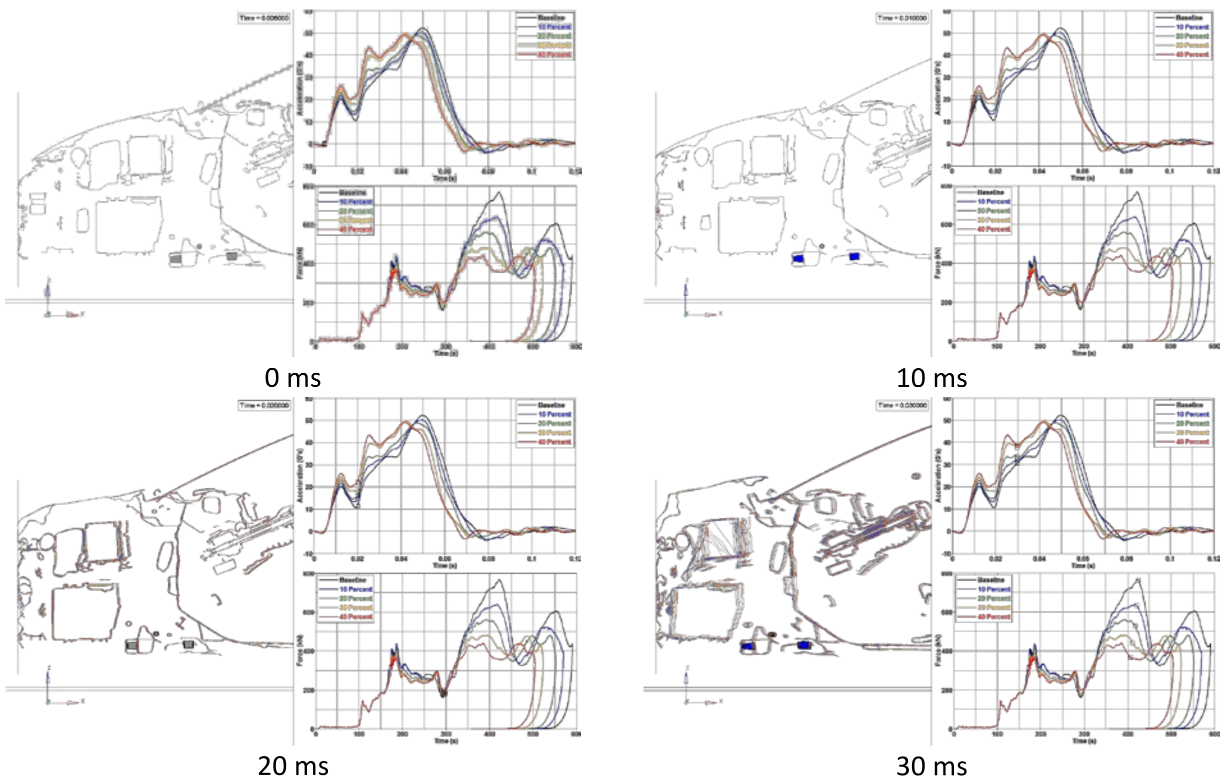
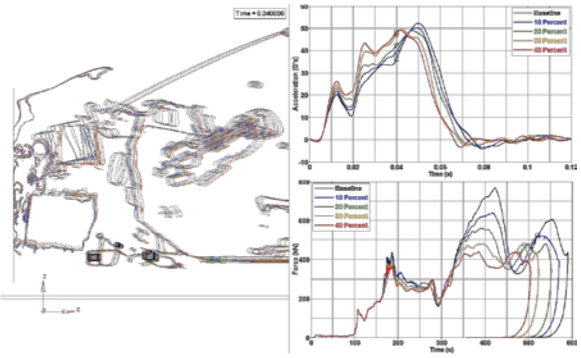
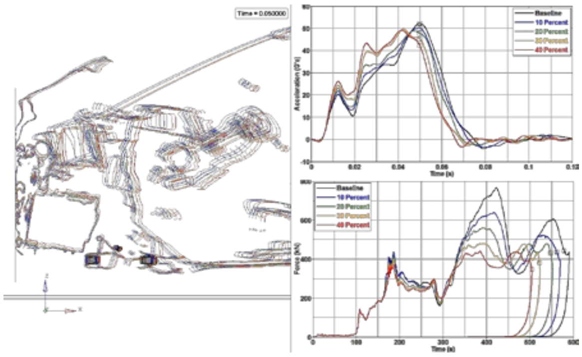
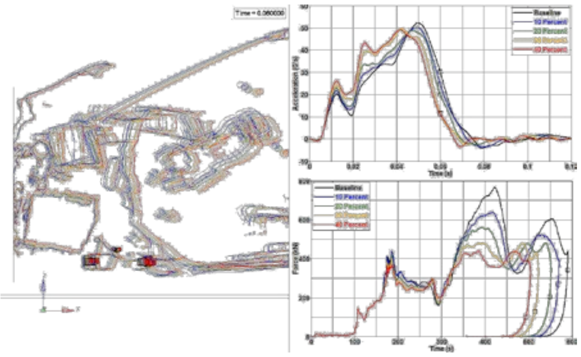


Fig. 2. Model section cut along with X-Acceleration and Force-Displacement curve comparison showing the response of the Mid-Size Mass Reduced (MSMR) vehicles overlay through 70 ms


40 ms


50 ms


60 ms

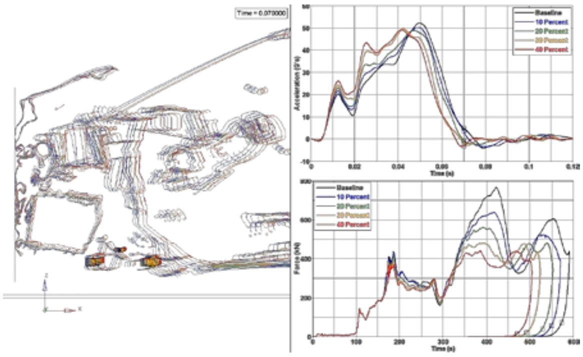

70 ms

Fig. 2. Model section cut along with X-Acceleration and Force-Displacement curve comparison showing the response of the Mid-Size Mass Reduced (MSMR) vehicles overlay through 70 ms (Cont.)

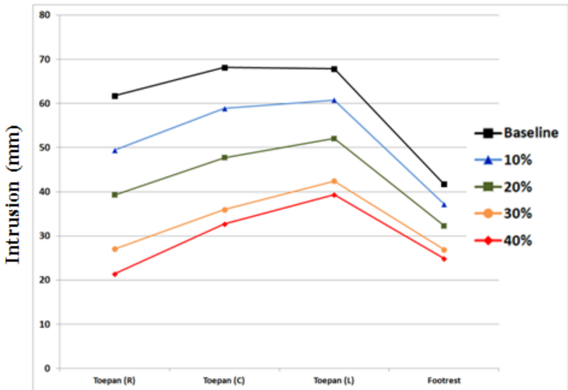


Fig. 3. Driver crashworthiness intrusion of NCAP frontal test.

The IIHS frontal Offset Deformable Barrier (ODB) test was performed using the 5 different vehicles: baseline (0%), 10%, 20%, 30% and 40% MSMR models. The test speed for all the simulations was 64 km/h (40 mph) and the Livermore Software Technology Corporation (LSTC) ODB FE model with solid elements was used for the simulation [10]. The IIHS frontal offset test is described in the IIHS test protocol manual [9].

The average accelerations in the x-direction from the right and left rear seat accelerometers for all the models are shown in Figure 4. The maximum accelerations for the lighter vehicles did not reach the baseline maximum acceleration (less than 3 G's). However, the maximum acceleration of the MSMR vehicles occurs sooner. The velocity time to zero and the maximum vehicle displacement are reduced with the mass reduced models. The typical IIHS intrusions of all the models are shown in Figure 5. The graph shows that the lighter the MSMR vehicle, the less the compartment intrusion that is observed than that of the baseline vehicle.

For the vehicle-to-vehicle test set-ups, 2 vehicles, the baseline mid-size vehicle and a pick-up truck (Silverado), and 2 configurations were performed based on 100% and 40% vehicle overlap. The striking and the MSMR struck vehicles were each travelling at 56 km/h (35 mph) test speed in opposite directions.

For the baseline vehicle striking the MSMR vehicles at 100% overlap, the average x-acceleration curves are shown in Figure 6. The maximum accelerations for the lighter vehicles reach values 18% higher than the baseline maximum acceleration. The driver intrusion is shown in Figure 7. The intrusion decreases as the

MSMR model mass is reduced. A localized exception was observed that is due to the sequence of events and bending modes of the sheet panels.

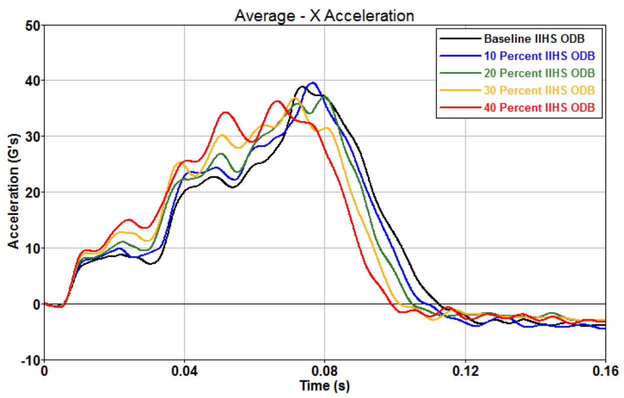


Fig. 4. Average rear seat acceleration comparison of IIHS 40% offset frontal test.

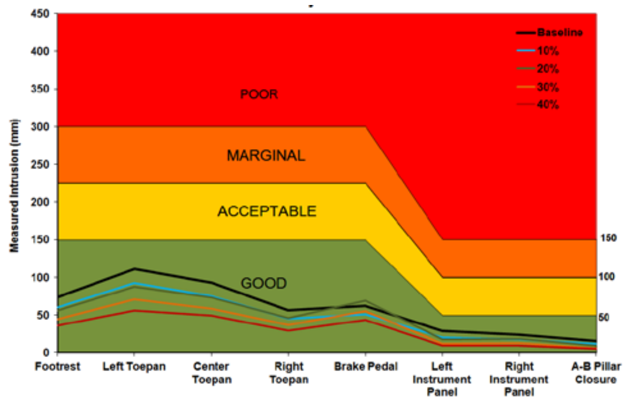


Fig. 5. Crashworthiness intrusion of IIHS 40% offset frontal test.

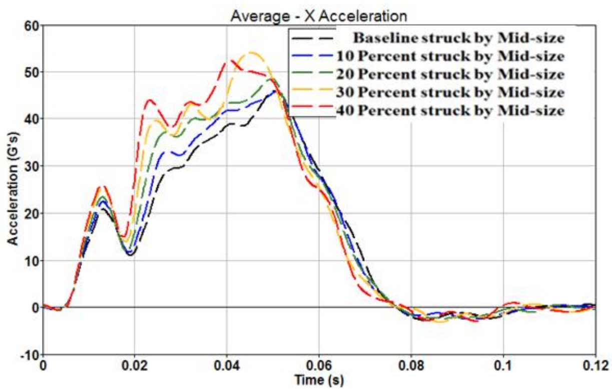


Fig. 6. Average rear seat acceleration comparison of struck MSMR vehicles at 100% overlap with baseline.

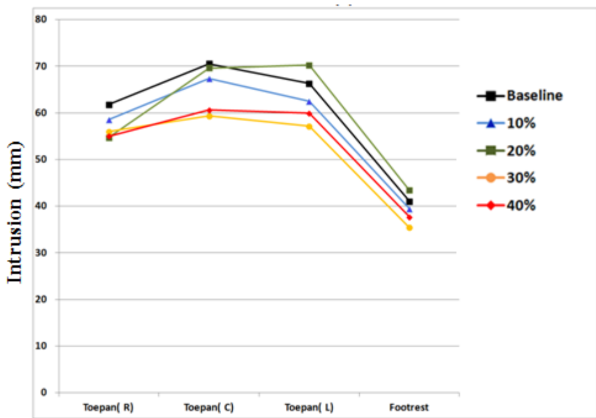


Fig. 7. Crashworthiness intrusion of struck MSMR vehicles at 100% overlap with baseline

For the pick-up truck (Silverado) striking the MSMR vehicles at 100% overlap, the average x-acceleration curves are shown in Figure 8. The maximum accelerations for the lighter vehicles reach values 55% higher than the baseline maximum acceleration. The intrusion is shown in Figure 9 and shows different patterns. The intrusion increases as the MSMR model mass is reduced. The intrusion increase happens because the pick-up truck rails do not engage the MSMR vehicle rails, driving the MSMR engines into the occupant compartment.

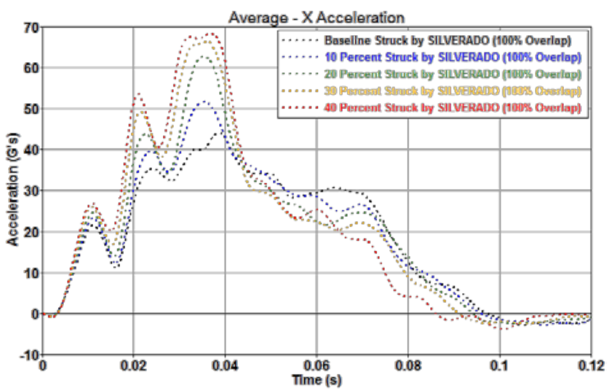


Fig. 8. Average rear seat acceleration comparison of struck MSMR vehicles at 100% overlap with SUV (Silverado).

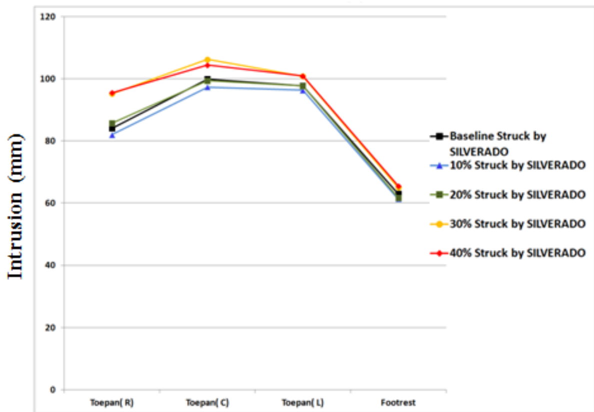


Fig. 9. Crashworthiness intrusion of struck MSMR vehicles at 100% overlap with SUV (Silverado)

For the baseline vehicle striking the MSMR vehicles at 40% overlap, the average x-acceleration curves are shown in Figure 10. The maximum accelerations for the lighter vehicles reach values 40% higher than the baseline maximum acceleration. The intrusion is shown in Figure 11. The intrusion decreases as the MSMR model mass is reduced. The values are close to the baseline model intrusions.

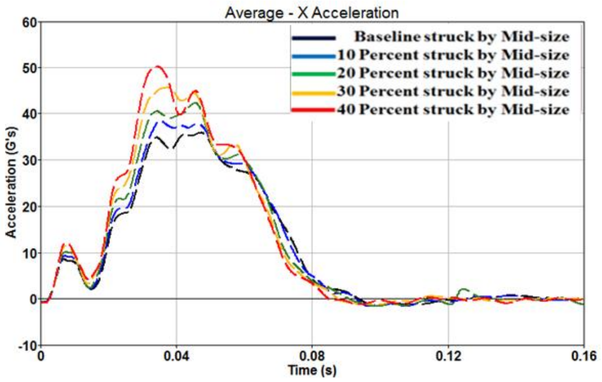


Fig. 10. Average rear seat acceleration comparison of struck MSMR vehicles at 40% overlap with baseline.

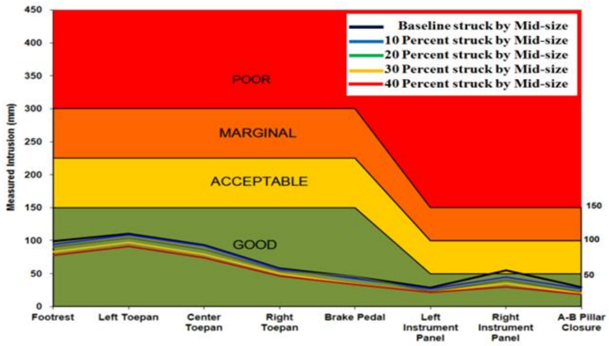


Fig. 11. Crashworthiness intrusion of struck MSMR vehicles at 40% overlap with baseline

For the pick-up truck (Silverado) striking the MSMR vehicles at 40% overlap, the average x-acceleration curves are shown in Figure 12. The maximum accelerations for the lighter vehicles reach values 57% higher than the baseline maximum acceleration. The intrusion is shown in Figure 13. The intrusion decreases as the MSMR model mass is reduced. In these set of simulations, the Silverado lower rail buckles due to the loading from the MSMR vehicles.

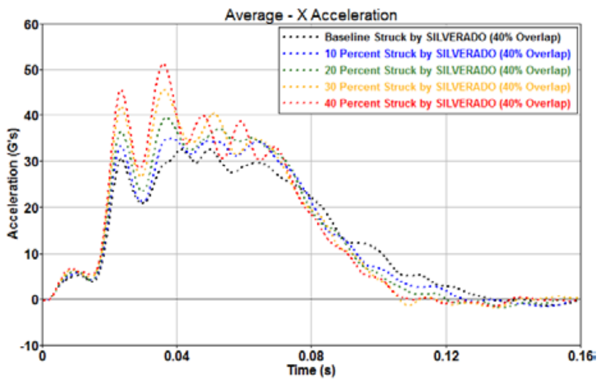


Fig. 12. Average rear seat acceleration comparison of struck MSMR vehicles at 40% overlap with SUV (Silverado).

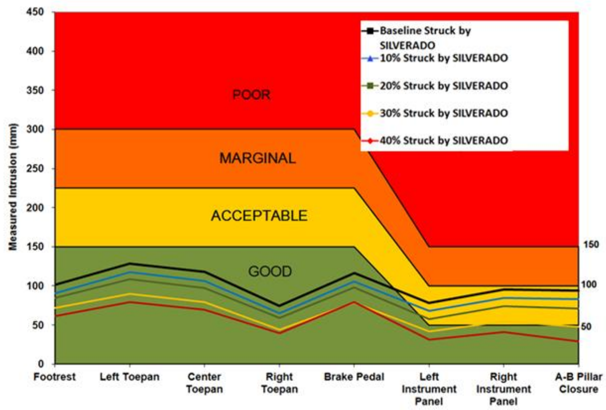


Fig. 13. Crashworthiness intrusion of struck MSMR vehicles at 40% overlap with SUV (Silverado)

IV. Discussion

The average x-acceleration increases locally and occurs sooner than the baseline as the MSMR model mass is reduced. The maximum average x-acceleration for the vehicles in the NCAP and IIHS crashes are within 8% of the baseline values as MSMR model mass is reduced. The NCAP and IIHS results were expected based on the mass reduction effects on the kinetic energy (½ Mass x Velocity^2). However, the vehicle-to-vehicle crash accelerations are different. The maximum average x-accelerations for vehicle-to-vehicle configurations increase and reach higher values (up to 57%) than the baseline values as MSMR model mass is reduced. The increase in acceleration and timing shift affects the velocity time to zero. The maximum velocity time to zero decreases by up to 19 ms as MSMR model mass is reduced for all frontal configurations.

As the MSMR model mass is reduced, the average x-velocity time to zero value is decreased. The rapid drop in time to zero velocity is produced by the high accelerations. The drop in average x-velocity time to zero corresponds to an increase in the Delta-V. O'Day and Flora (1982) and Joksch (1993) found that the risk of a car driver being killed in a crash increased with the increase in change of speed [12]–[13].

The probability of fatality increases exponentially and is governed by equation 4. The risk is calculated from the Delta-V (in mph).

$$\Pr obability.of.fatality = \left(\frac{Change.in.Speed}{71} \right)^4 \quad (4)$$

The change in speed (Delta-V) is measured from the average x-velocity for each simulation. The Delta-V of the MSMR vehicles is about 64 km/h (40 mph) for the NCAP tests, increases from 63 km/h (39.2 mph) to 74.2 km/h (46.1 mph) when struck by the baseline mid-size car with 100% overlap, and increases from 79.5 km/h (49.4 mph) to 88.0 km/h (54.7 mph) when struck by the Silverado with 100% overlap.

The Delta-V of the MSMR vehicles is around 69.2 km/h (43 mph) for the IIHS ODB tests (initial speed is 64 km/h, 40 mph), increases from 57.8 km/h (35.9 mph) to 68.2 km/h (42.4 mph) when struck by the baseline mid-size car (closing speed is 56 km/h, 35 mph) with 40% overlap, and increases from 76.9 km/h (47.8 mph) to 85.9 km/h (53.4 mph) when struck by the pick-truck truck (Silverado) with 40% overlap (closing speed is 56 km/h, 35 mph). Using equation 4, the probability of fatality for all cases is calculated and the results are shown in Table 2.

The probability of fatality remains the same at 10% in an NCAP test configuration, increases from 9% to 18% when the MSMR vehicle is struck by the baseline mid-size car with 100% overlap, and increases from 23% to 36% when the MSMR vehicle is struck by the Silverado with 100% overlap. Similarly, the probability of fatality remains the same at 13% in an IIHS test configuration, increases from 7% to 13% when the MSMR vehicle is struck by the baseline mid-size car with a 40% overlap, and increases from 21% to 32% when the MSMR vehicle is struck by the Silverado with a 40% overlap.

Field Data Concerning Safety, Mass and Size of Vehicle

All other things being equal, research has established that drivers of smaller, lighter cars have a higher risk of fatality than drivers of larger, heavier cars [14]. Evans derived a function that separated the mass effect from the size effect for two-car collisions [5]. He postulated a car with mass M_1 and overall length L_1 impacting a car with mass M_2 and overall length L_2. He derived two key relationships. His first formula, equation 5, was in terms of $r_{1,2}$ and is the risk faced by the driver of car 1 in a collision with car 2.

$$r_{1,2} = 93.34 \times \frac{\left(\frac{M_2}{M_1} \right)^{1.79}}{\left(L_1^{2.45} + L_2^{2.45} \right)} \quad (5)$$

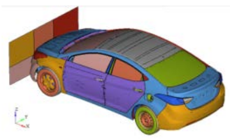
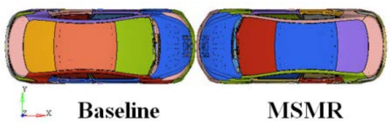
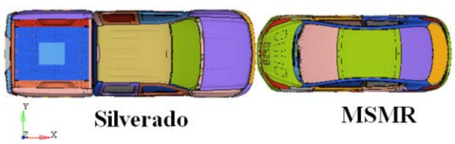
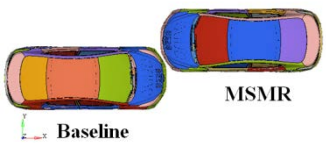
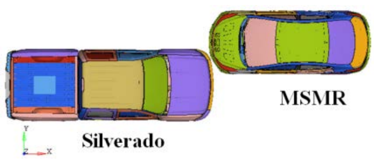
In deriving the equation, a constant, which turned out to be 93.34, was chosen so that the risk to a driver in a typical 1,400 kg car of overall length 4.8 m crashing into an identical car gives $r_{1,2}$ = 1.

Similarly, $r_{2,1}$ is the risk faced by the driver of car 2 in a collision with car 1. The total risk, or the risk to society, is the sum of $r_{1,2}$ and $r_{2,1}$, so r_{total} = $r_{1,2}$ + $r_{2,1}$. Using equation 5, the total risk to society is

$$r_{total} = 93.34 \times \frac{\left(\frac{M_2}{M_1}\right)^{1.79} + \left(\frac{M_1}{M_2}\right)^{1.79}}{\left(L_1^{2.45} + L_2^{2.45}\right)}. \quad (6)$$

TABLE II

ACTUAL MASS REDUCTION MODELS PROPERTIES

Test Configuration	MSMR Models	Struck by	Delta V km/h (mph)	Probability of Fatality
	Baseline	NCAP 56.3 km/h (35 mph)	64.4 (40.0)	0.10
	10 %		64.5 (40.1)	0.10
	20 %		64.2 (39.9)	0.10
	30 %		64.4 (40.0)	0.10
	40 %		64.7 (40.2)	0.10
	Baseline	Mid-Size 56.3 km/h (35 mph)	63.1 (39.2)	0.09
	10 %		65.7 (40.8)	0.11
	20 %		68.9 (42.8)	0.13
	30 %		71.8 (44.6)	0.16
	40 %		74.2 (46.1)	0.18
	Baseline	Silverado 56.3 km/h (35 mph)	79.5 (49.4)	0.23
	10 %		81.8 (50.8)	0.26
	20 %		84.2 (52.3)	0.30
	30 %		86.4 (53.7)	0.33
	40 %		88.0 (54.7)	0.36
	Baseline	IIHS ODB 64.4 km/h (40 mph)	69.2 (43.0)	0.13
	10 %		69.2 (43.0)	0.13
	20 %		69.4 (43.1)	0.14
	30 %		69.0 (42.9)	0.13
	40 %		68.4 (42.5)	0.13
	Baseline	Mid-Size 56.3 km/h (35 mph)	57.8 (35.9)	0.07
	10 %		60.7 (37.7)	0.08
	20 %		63.1 (39.2)	0.09
	30 %		66.1 (41.1)	0.11
	40 %		68.2 (42.4)	0.13
	Baseline	Silverado 56.3 km/h (35 mph)	76.9 (47.8)	0.21
	10 %		79.3 (49.3)	0.23
	20 %		81.9 (50.9)	0.26
	30 %		84.5 (52.5)	0.30
	40 %		85.9 (53.4)	0.32

Equation 6 for total risk suggests that mass decrease tends to have a regressive effect on the total driver fatality risk while reducing the overall length of either car increases the total risk to both drivers.

In the following table, the safety of the MSMR approach is contrasted with the safety of reducing the overall length on the average. The risk faced by the driver in vehicle 1 colliding with vehicle 2 is shown in Table 3. Following Evans, vehicle 2 is assumed to be a 1,400 kg car of overall length 480 cm. The $r_{1,2}$ is calculated using equation 3. Recall that equation 3 was normalized to equal one for two identical cars of 1,400 kg mass and 480 cm overall length colliding. Table 3 shows the decrease in fatality risk of the MSMR approach compared with reducing the overall length on the average as the mass of the car is lowered. Also in Table 3, Evans' total risk or the risk to society for the drivers in both cars is presented based on equation 6. Table 3 shows the decrease in total fatality risk of the MSMR approach compared with reducing the overall length on average as the mass of the car is lowered.

It turns out that the MSMR method is safer compared to an average car that is made smaller as the mass is reduced.

The toepan intrusion decreases for all models as MSMR model mass is reduced, except for the Silverado striking the MSMR vehicle at 100% overlap. The toepan intrusions for the Silverado striking the MSMR vehicle at 100% overlap increase due to the engagement of pick-up truck rails with the MSMR vehicle engine.

TABLE III

REDUCTION IN FATALITY RISK FOR DRIVER IN CAR 1 AND REDUCTION IN TOTAL FATALITY RISK USING MSMR APPROACH

	Baseline	10%	20%	30%	40%
Reduction in Fatality Risk, $r_{1,2}$ using MSMR (%)	0	2.9	5.9	8.6	10.5
Reduction in Fatality Risk, r_{total} using MSMR (%)	0	3.0	5.8	8.5	10.5

V. CONCLUSIONS

Future vehicles are subjected to new fuel efficiency requirements which require vehicles primarily to reduce additional mass. Lighter vehicles are going to be present alongside the older and heavier fleet, which changes the crashworthiness dynamics. Vehicles that are comparable in mass and size have similar crashworthiness characteristics since they meet federal regulation and consumer information test requirements. When the vehicle's mass and size are changed, the vehicle crashworthiness is altered. This study investigates the crashworthiness of a mid-size vehicle model using Finite Element (FE) analysis. The mass is reduced by maintaining the vehicle structure strength load-bearing portion and keeping the size unchanged. The center of gravity characteristics are maintained for different mass reduced models.

For NCAP and IIHS frontal impact test configurations, the mid-size mass-reduced (MSMR) models show no significant increase in injury risk when the vehicle mass is reduced. For these two tests, mass reduction is suggested to be easily attained while maintaining a good vehicle safety rating.

When the vehicle-to-vehicle crash scenario is addressed, the MSMR vehicle crashworthiness is different. When heavy vehicles strike lighter vehicles, the mass reduced models correspond in general to an increase in the maximum acceleration and to a decrease in velocity time to zero. Localized decreases in the toepan area intrusions are observed, with the exception of one test configuration, which had an increase in the toepan intrusions. These test configurations correspond to past findings in the analysis of real-world crash data. The fatality risk of real-world crashes increases with the increase in acceleration and decrease in velocity time to zero. Additional work to reduce such risk can be achieved by redesigning the front structure and the restraint systems to accommodate the aggressivity in the crush pulse.

VI. Acknowledgement

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