

## FRONT SEATBACK STRENGTH IMPROVEMENTS STUDY IN REAR CRASH EVENTS

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### ABSTRACT

National Highway Safety Administration (NHTSA)'s seat back standard FMVSS No. 207 [1] establishes a minimum strength requirement to reduce occurrence of seat back collapse in rear crash events. NHTSA also has a separate standard for head restraints. FMVSS No. 202a, that is intended to mitigate whiplash injuries in rear end crashes. In general, seat backs in current production vehicles will not significantly deform or collapse when subjected to the FMVSS No. 202a test pulse. Thus, a more severe test impulse would be needed to demonstrate a change in seat back performance in a rear impact. Recently rear crash events had fatal injuries to rear seat occupants that was attributed to the collapse of a front seat back. This study was to study seat back design changes that could reduce seat back motion in high speed rear impact [2]. The Bio-RID II dummy was used for testing and simulation in this study. This paper provides details of seat back strength changes from a baseline 2014 Honda Accord.

### INTRODUCTION

In this study, detailed Finite Element (FE) models were developed for manual and power operated seats of 2014 Honda Accord vehicle. The FE models were then validated by comparing them to test results of low speed quasi-static seat back pull test reaffirming similarity between FE seats and test seats. In addition, FMVSS 301 high speed rear impact test [3] and simulations were carried out with rear seat occupant models to investigate front seat back dynamic rotation, post-test deformation and injury measures of rear seat occupant. Structural countermeasures were developed to reduce dynamic seat back rotation beyond 20°. Further countermeasures were verified to ensure no impact on whiplash requirement by comparing results from low speed front seat head restraint test and simulation. The mass and cost changes due to structural updates going from current seat design to improved seat design was also reported. This paper provides brief description of FE seat model developed and countermeasure implementation.

### FINITE ELEMENT SEAT MODEL DEVELOPMENT

The vehicle selected for this study was 2014 Honda Accord. Both manual and power seats were considered for investigation. A manual seat with 4-way seat adjustment mechanism and a power seat with 6-way seat adjustment mechanism were used for measurement and testing. In order to develop FE models, the physical seats were scanned and exported to stereolithographic (STL) digital format readable in computer aided design (CAD) tools. The scanned data was processed in CAD tool and meshed in an FE tool accordingly. The thicknesses of the parts were recorded, and the material grades were estimated based on a hardness tests performed on the required seat parts. The scanned CAD data and the FE models of the manual seat and power seat are shown in Figure 1. *Scanned seat and FEA model of Manual and Power seat*. The FE models are also shown in different material grades (provided in the table insert).

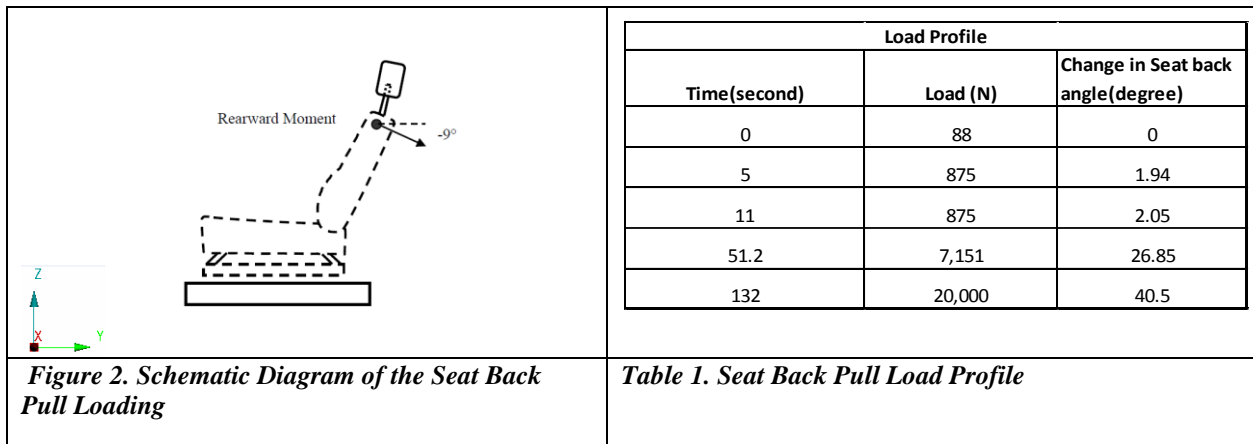


**Figure 1. Scanned seat and FEA model of Manual and Power seat**

Separate LS-DYNA FE models were developed for manual and power seats by appropriate FE connections and assembling techniques. This included the detailed modeling of kinematic joints of seat mechanism and seat back recliner mechanism; assembling seat cushion foam and recliner mechanism. The seat cushion foam was pre-deformed to accommodate the occupant shape which was used in the later section of FMVSS No. 301 simulations.

### SEAT BACK PULL TEST

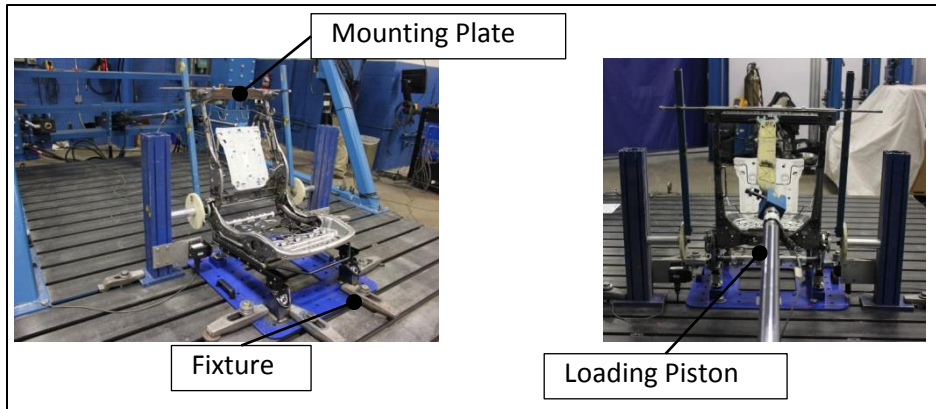
Seat back strength was chosen as the validation criteria to compare FE seat model with physical test. This test was conducted on the manual seat and power seat without cushions and plastic trim in a quasi-static loading condition. The necessary seat fixtures were fabricated to mount the seat at four seat bolts at the four corners of the seat base. A similar loading method stated in FMVSS No. 207 Rearward Moment (49 CFR 571.207 S4.2d, dated 10/1/2016), was used, but it was applied until the seat collapsed. Load was applied at -9 degree about y axis as shown in Figure 2.



**Figure 2. Schematic Diagram of the Seat Back Pull Loading**

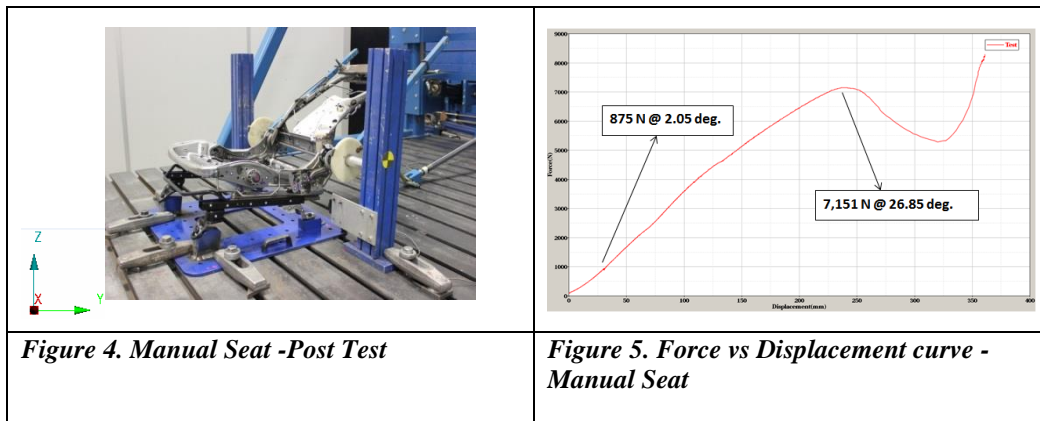
**Table 1. Seat Back Pull Load Profile**

For understanding purpose, seat back pull test setup of the manual seat is briefly described. Seat back pull test setup is shown in Figure 3. The seat was positioned in full down, full rear track position. Load was applied at mounting plate on top of the seat back frame in rearward direction. The load profile shown in Table 1 was used to pull the seat back. The pull load was applied in the rearward direction from 88 N (at 0 seconds) to 875 N (at 5 seconds), and then the load was maintained for the next 6 seconds (per the FMVSS 207 quasi static seat back strength test).



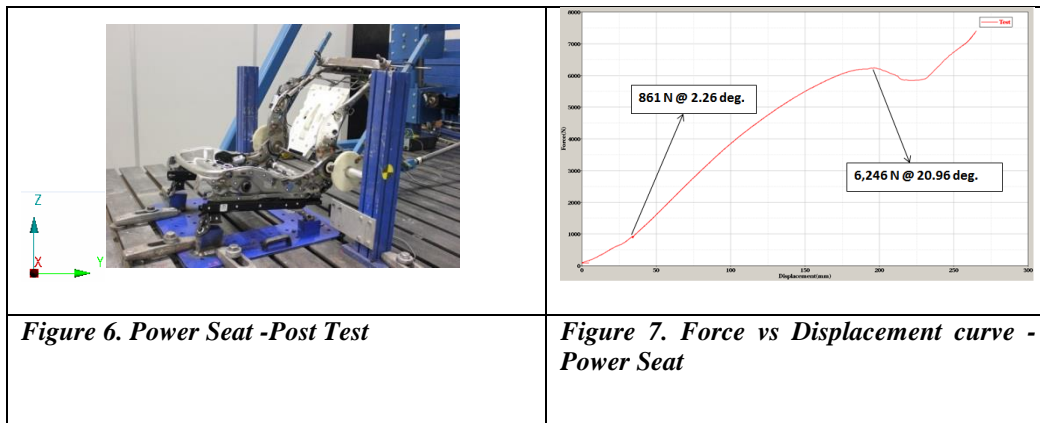
**Figure 3. Seat Back Pull Test Seat Setup – Manual Seat**

Manual seat post-test and Force-Displacement curve from the test are shown in Figure 4 and Figure 5 respectively.



The seat back pull test results of manual seat showed that until 11 seconds there is no deformation or failure. The deformation is observed on the seat bottom frame at the connecting flanges. Significant deformation occurred symmetrically at the seat back frame at the weld joint location. There were no failures or deformation observed on the recliner mechanism. The collapse of the seat started when the seat back angle reached 50.1 degrees from the normal. It was found that the manual seat collapsed at 7,151N.

Similar to the manual seat, the seat back pull test was conducted for power seat in the same full down, full rear track position. Power seat post-test and Force-Displacement curve from the test are shown in Figure 6 and Figure 7 respectively.



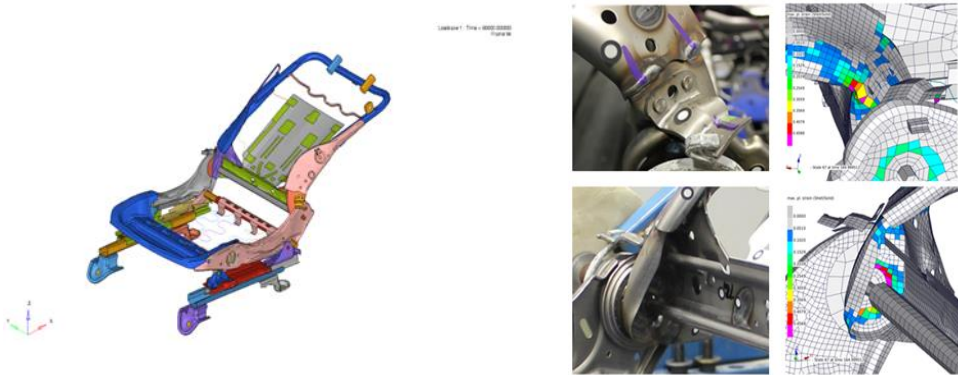
The test results showed that there was no deformation or failures observed in the power seat until 11 seconds. Unlike the manual seat, the power seat frame deformed non-symmetrically due to motor and mechanism in the seatback frame. It was found that the power seat collapsed at 6,246N. The left-hand side (LHS) seat frame deformed more than the right-hand side (RHS) seat frame. (LHS) frame collapsed first at 37.1 degrees and (RHS) collapsed later at 20 degrees respectively.

The detailed test reports for both manual seat and power seat has been provided [4].

### SEAT BACK PULL TEST SIMULATION

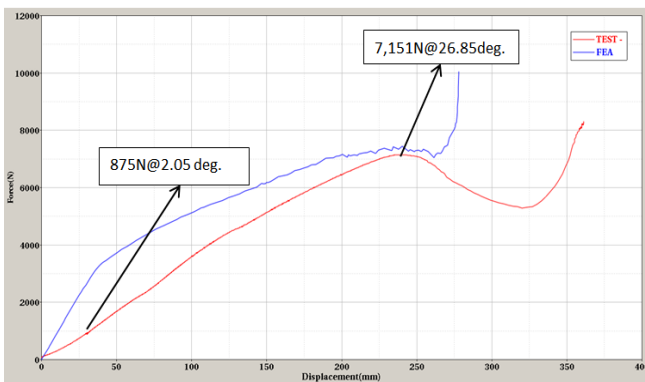
FE simulation of seat back pull test is a quasi-static simulation as per the loading condition. The FE simulation was carried out in quasi-static boundary condition for both manual and power seats. The FE seat models were setup to represent the physical tests accordingly. LS-DYNA simulations were run in implicit mode for 60 seconds. FE simulation results of the manual seat and power seat back were compared with the corresponding physical tests.

Figure 8 shows the global deformation of the collapsed seat frames and the comparison of test and FE simulation at the failed area for manual seat.



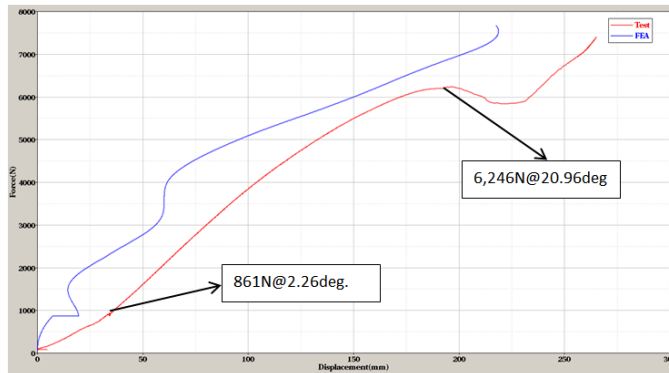
**Figure 8. Global deformation of the Seat Frame and Similar Deformation of Test vs FEA – Manual Seat**

The gussets folded inward and failed symmetrically in both test and FEA. In addition to the frame deformation, the seat back strength was compared in terms of stiffness or Force-Displacement (FD) plots. The comparison of FD curves of FE simulation and physical test is shown in Figure 9. The FD curve shows a “CORA” [5] correlation rating of about 78%.



**Figure 9. Force vs. Displacement Curves – Manual Seat**

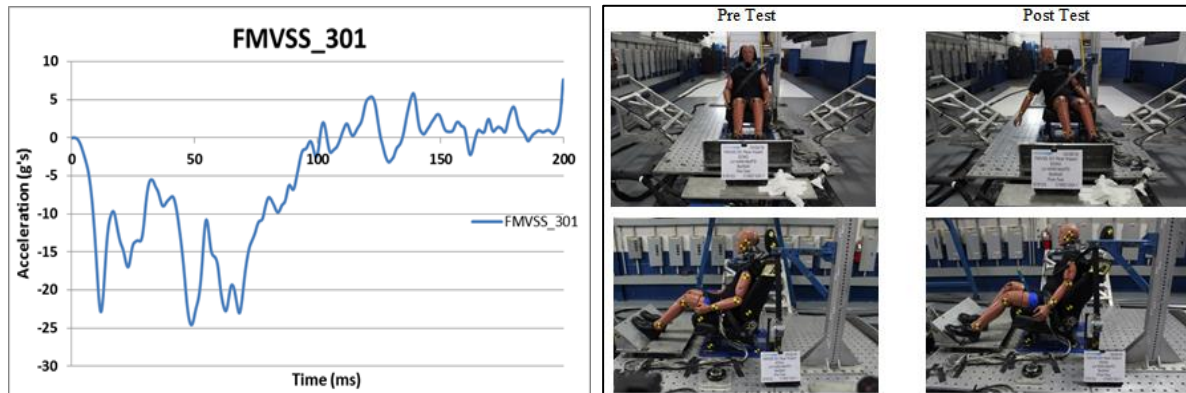
Similarly, the power seat FE model was also set up to full down, full rear position by adjusting the seat position mechanism. Same method was followed from the manual seat modeling to set up and run power seat pull test simulation. FE simulation results of the power seat back pull test were compared with the physical test. The gussets folded non-symmetrically due to the motor that is located on the right-side gusset, the (LHS) frame collapsed first at 37.1 degrees and (RHS) collapsed later at 20 degrees respectively. The comparison of FD curves of FE simulation and physical test is shown in Figure 10. The FD curve shows a “CORA” [5] correlation rating of about 78%. Thus, both the manual and power FE seat were modeled with acceptable detail and accuracy.



**Figure 10: Force vs. Displacement Curves – Power Seat**

### REAR IMPACT FINITE ELEMENT MODEL DEVELOPMENT

This study was intended to investigate seat design changes to reduce front seat back rotation in rear crash events. It was decided to carry out FE simulations with rear seat passenger using an FMVSS No. 301 crash pulse. Rear impact FE models were developed using a manual seat and a power seat. Each seat model was positioned into an existing 2014 Honda Accord full vehicle model and validated against the sled test results. The rear impact vehicle pulse from 2014 Honda Accord rear impact simulation was used as sled pulse in the test. The sled tests were conducted for both manual and power seats on the physical sleds using this pulse. For example, the rear impact vehicle pulse and the sled test (before and after test) are shown in Figure 11 for manual seat.



**Figure 11. FMVSS No. 301 Rear Impact Vehicle Pulse and Sled Setup**

The manual seat was tested in mid track and full down seat position with seat back initial position of 18 degrees. The power seat was tested in full rear track and full down seat position with seat back initial position of 18 degrees. The reason for conducting the sled tests for two different seat positions is to understand the seat back strength requirements for nominal and extreme conditions of occupant seating. Occupant characteristics including head acceleration, neck injury parameters and seat back measurements were recorded appropriately. Measured from the

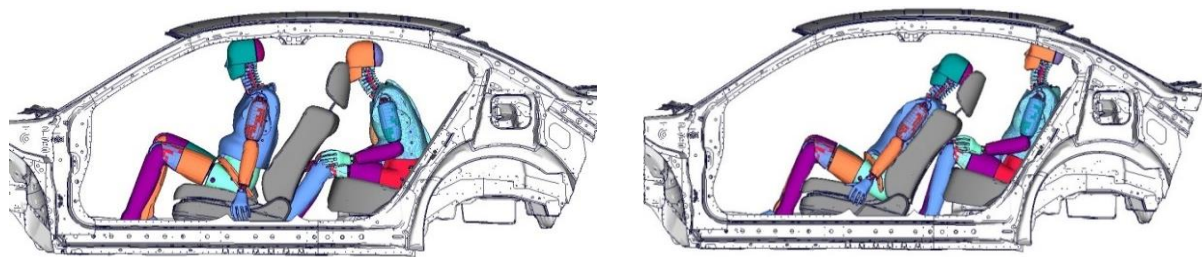
seat back normal, manual seat recorded a dynamic seat back deflection of 38.4° and post-test static permanent deflection of 9.4°. The test conducted on the power seat recorded a dynamic seat back rotation of 38.5° and post-test static permanent deflection of 9°. The FE animations and physical test video showed similar kinematics. The comparisons of HIC, Nij are listed in Table 2. Similar tests were conducted for the power seat, and the summary of the test and FEA results are also included in the table.

**Table 2. FMVSS 301 Sled Test FE Simulations and Test Comparison – Manual Seat and Power Seat**

No.	Injury measures	Manual Seat		Power Seat	
		FEA	Test	FEA	Test
1	HIC 15	80	77	55	76
2	NIJ	0.18	0.28	0.42	0.08

### SEATBACK STRENGTH REQUIREMENT

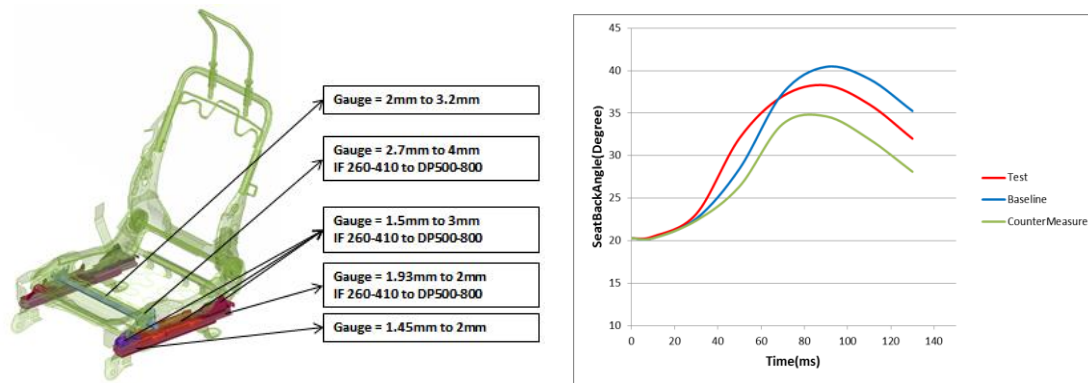
The next step of the research study was to understand the required front seat back strength to avoid interaction with the rear seat occupant and potential injuries in high speed rear crash. For this purpose, first FMVSS No. 301 high speed rear impact simulations were carried out with rear seat occupants using the validated seat models. The BioRID II FE dummy model was used as rear seat passenger and positioned on the rear seat behind the driver seat. The necessary rear seat head restraint was modeled and integrated in the full vehicle representation of FE model. Unbelted rear seat occupant condition was chosen to be a worst-case scenario. LS-Dyna simulations were run for both manual and power seat. The front seat back rotation and the interaction of rear seat occupant with the front seat were observed. The FE simulations of both manual and power seat clearly showed that the front seat back impacted on the unbelted rear seat passenger behind the driver seat. The severity of front seat with rear seat occupant interaction is shown in Figure 12. The front seat impact on the rear seat occupant knee showed significant contact and femur force which was above 3.5 kN with the seat back angle of 39 degrees with respect to vertical and knee clearance of only 8.06 mm. Cantor, A. (2000) Seatback Strength and Performance study suggests that safe seat back rotation after crash is 15 degrees from initial position [6]. For this study, 20 degrees of seat back rotation is considered as safe criteria. It can be observed that the seat rotation after impact is greater than 35 degrees which is greater than 20 degrees from initial position. The seat back mechanism will be redesigned to limit front seat rotation.



**Figure 12. Front Seat Back and Rear Seat Occupant Interaction**

### SEATBACK STRENGTH IMPROVEMENTS

Having observed that the seat back rotation could contact rear seat passengers in a high speed crash, it was decided to develop necessary structural countermeasures. These countermeasures were implemented on manual and power seat, and FE simulations were run to predict the improvements. Investigation of FE simulation showed that the seat bottom upward movement by the 4-way or 6-way seat mechanism influenced the seat back frame rotation more than the deformation of the seat frame alone. Therefore, Gauge and Grade (2G) optimization was undertaken on the seat bottom frame and bracket members. This approach showed good improvements in reducing the seat back dynamic rotation. The seat bottom frame and mechanism support parts were optimized, and FE simulations were compared with the baseline seats. The gauge and grade changes of the seat bottom frame are shown in Figure 13.



**Figure 13. Seat Bottom Countermeasure and Seat Back Angle (Manual Seat)**

Finally, the countermeasures were validated by means of FE simulations. The 2G optimized seat models were integrated into the FMVSS No. 301 FE model, and simulations were carried out. The outcome of the FE prediction revealed that the seat back angle, knee clearance and knee impact force of the rear seat occupant were reduced due to the effectiveness of the countermeasure. Table 3 shows a comparative summary of the baseline seats and countermeasure seats. In addition to the seat back rotation angle, seat frame-to-knee clearance and femur forces were also included as target performance criteria. When compared to the respective baseline seats, countermeasure seats showed significant improvements. The manual seat countermeasure showed good knee clearance. The femur force is found to be slightly higher, but 3.1 kN is within acceptable limit as per the knee injury criteria. In case of power seat countermeasure, the improvements are seen in all three criteria.

**Table 3. Countermeasure improvements for Manual Seat and Power Seat**

No	Criteria	Target	Manual Seat		Power Seat	
			Baseline	Counter-measure	Baseline	Counter-measure
1	Seat back angle	< 35 deg.	39 deg.	35.2 deg.	38 deg.	35 deg.
2	Seat frame to Knee clearance	> 10 mm	8.06 mm	27.68 mm	3.76 mm	17.23 mm
3	Femur force	< 1.5 kN	5 kN	3.1 kN	3.5 kN	1 kN

The countermeasures were similar on the seat bottom frame parts for both manual and power seats. While structural countermeasures were carried out, it was desired to estimate the cost impact of changing the current design. The cost estimation was done for the baseline and countermeasure seats using standard MIT cost model template. The gauge and grade change influenced an increase in the mass of 2.13 kg and corresponding cost increase of \$1.94 for the manual seat, and an increase of 1.69 kg and \$4.62 for power seat. Cost Impact of the countermeasure seats are shown in Table 4.

**Table 4. Cost Impact of Countermeasure Seats**

<b>No.</b>	<b>Description</b>	<b>Manual Seat</b>	<b>Power Seat</b>
1	Baseline seat weight (kg)	18.81	23.41
2	Countermeasure seat weight (kg)	20.94	25.10
3	Baseline weight of parts affected (kg)	3.87	4.13
4	Countermeasure weight of parts affected (kg)	6.00	5.82
<b>5</b>	<b>Δ weight (kg) / seat</b>	<b>2.13</b>	<b>1.69</b>
6	Baseline cost of parts affected	\$2.24	\$ 9.39
7	Countermeasure cost of parts affected	\$4.17	\$ 14.01
<b>8</b>	<b>Δ cost / seat</b>	<b>\$1.94</b>	<b>\$ 4.62</b>
9	Cost / kg increase	\$0.91	\$ 2.73

It is worth mentioning that FMVSS No. 202a low speed requirement was also carried out to confirm that the developed countermeasures do not affect the whiplash requirement without much deviation from baseline or test.

## CONCLUSIONS AND RECOMMENDATIONS

The seat back strength improvement study for the driver seat was carried out for manual and power operated seats of 2014 Honda Accord vehicle by utilizing CAE techniques in a systematic approach. The dynamic seat back rotation of the front seat against the rear seat occupant was investigated. It was found from FE simulations that the rear seat occupant exhibited significant injury potentials when the front seat back was rotated more than 20 degrees from initial position. Therefore, the seat back strength was improved by implementing necessary countermeasures on the seat bottom frame parts. Further, these countermeasure changes to manual and power seat show minimal cost impact.

It can be noted that the study was limited to one type of occupant which was 50th percentile male. Front seat strength observation in rear impact scenario and front seat back rotation onto rear seat occupant involved using only Bio-RID II 50th percentile male dummy model. The observation of front seat back dynamic rotation causing potential injuries to rear seat occupant and the countermeasures are based on the occupant injuries of 50th percentile male. However, the severity of the injury can vary depending on different occupant (toddlers, children, adult, etc.) and different riding condition such as belted, unbelted, add-on restraint systems.

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