

15-Passenger Van Safety Review

Phase III:

TRANSPORT CANADA

PAIRED SIDE IMPACT CRASH TESTING of a 15 PASSENGER VAN & an MFAB

INTERNAL RESEARCH REPORT ASFB 11- 05

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DISCLAIMER

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EXECUTIVE SUMMARY

In January 2008, eight passengers died after the 15-passenger van they were travelling in was struck, at highway speed, by a tractor-trailer near Bathurst, N.B.. On September 30, 2010, former Transport Canada Minister Strahl committed the department to conduct a crash test of a 15-passenger van as requested by a lobby group of concerned citizens with a strong personal interest in van and bus safety for student transportation (www.vanangels.ca).

The objective of the test was to compare the protection available to restrained occupants of a 15-passenger van to that available to restrained occupants in an MFAB (Multi-Functional Activity Bus) in a severe side impact crash test. The severity of the tests, as determined by the size and impact speed of the bullet vehicle, was substantially greater than the severity of tests that are conducted for regulatory compliance and consumer safety rating side impact protection programs world-wide.

A model year 2011, Girardin multi-functional activity bus (MFAB) and a model year 2011 Ford E350 15-passenger van were each impacted at 90 degrees in the left rear axle by a 2009 Ford F150 pick-up truck travelling at 75 km/h. The rear axles were selected as the location of impact to ensure that the striking bullet impacted structural elements that were common to both test vehicles.

Seven crash test dummies were placed on board each vehicle in comparable seating locations. The dummies were representative in size to mid size men and small women. All were instrumented with state-of-the-art sensors in the head, chest and pelvis. All were seated upright and all were restrained with the available lap-shoulder seat belt. The motions of the dummies during the crash were recorded with several high speed video cameras.

The injury measures obtained from the dummies that were seated on the struck side of the E350 were generally greater than for the same dummies seated in the MFAB. Two of the three dummy heads were ejected from the window of the E350 while only an arm of the dummy seated in the rearmost row of the MFAB broke through the window.

The distance between the struck side dummies and the sidewalls influenced the injury measures. The interior trim profile of the E350 created an irregular profile and gap which allowed the dummy to accelerate and pivot, prior to striking the adjacent window. In the MFAB, the dummies were resting against the flat profile of the sidewall immediately prior to the crash. The outward motions of the heads were stopped by the rigid frames centered across each window in the MFAB.

In a real collision, the positions of the occupants at the moment of impact depend on their initial posture and the vehicle manoeuvres that take place just prior to the impact. Any

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behaviour or vehicle motion that causes the occupants to distance themselves from the surface they will eventually collide with during the crash, increases their risk of injury by allowing them to accelerate prior to hitting the surface. Also, since the window frames in the MFAB are not protected with energy absorbing materials, the risk of injury to the head during a collision involving human occupants cannot be discounted.

All of the dummies placed across the aisle from the impact point in both the E350 and the MFAB slipped out of the shoulder belts. In the E350 spacing between adjacent occupants was sufficiently constrained so that the far side dummies collided with the struck side dummies. In the MFAB the small female dummies either slid into the aisle or were catapulted into the aisle. The mid size male dummy in the MFAB crossed the aisle and collided with the struck side dummy. The dummy responses suggest that for human passengers exposed to these conditions there would be a risk of moderate to severe head injury and a risk of serious seat belt related injuries for all those seated on the far side of the impact, in both struck vehicles.

The results of the paired crash tests are comparable to side impact testing of other motor vehicles conducted by Transport Canada. As previously mentioned, the severity of the tests was substantially greater than the severity of tests that are conducted for regulatory compliance and consumer safety rating side impact protection programs. The effects on the dummy occupants were significant in both cases and so there will be no further testing at more severe conditions.

A known countermeasure that can reduce the risk of head injury for struck side occupants is inflatable curtain technology. The countermeasures to limit occupant ejection from the shoulder portion of the seat belt and prevent subsequent occupant to occupant contact in all types of passenger vehicles are still under development. Potential candidate measures may include improved designs of restraints and seats and the introduction of in-board side airbags.

As part of its regulatory program, Transport Canada will continue to assess the applicability of countermeasures for the protection of occupants of light-duty vehicles in general, during side impact collisions. This will be undertaken in the context of the Canada-U.S. Regulatory Cooperation Council and the activities thereunder.

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INTRODUCTION

In January 2008, eight passengers died after the 15-passenger van they were travelling in was struck, at highway speed, by a tractor-trailer near Bathurst, N.B.. On September 30, 2010, former Transport Canada Minister Strahl committed the department to conduct a crash test of a 15-passenger van as requested by a lobby group of concerned citizens with a strong personal interest in van and bus safety for student transportation (www.vanangels.ca).

The 15-passenger van is a preferred mode of transportation for a broad spectrum of applications and passenger types including; school and/ or senior outings, community events, and various shuttle services. An alternative mode of transportation for school related activities is the multi-functional bus (MFAB). The structure of these buses is similar to that of small school buses except that they are not equipped with certain safety features that are required for the secure embarkation and disembarkation of school children, for example, stop lamps and extendable stop signs.

The intention of the crashworthiness testing was not to replicate the tragic Bathurst collision. Because of the high speed at which the collision occurred (the closing speed was estimated by the collision investigators as being about 160 km/h) and the extreme difference in size between the striking transport truck and the 15-passenger van in question (the mass of the truck at the time of impact was estimated by the investigators to be more than five times that of the van), the crash was likely, far too catastrophic, for any known crashworthiness countermeasures to have prevented the loss of life. The objective of the test program therefore, was instead, to compare the protection available to restrained occupants of a 15-passenger van to that available to restrained occupants in an MFAB in a severe side impact crash test involving a bullet vehicle that is representative of the type that has typically been associated with causing serious injury in side impact collisions in the field. The bullet vehicles were of similar mass to both struck vehicles. These collisions nevertheless exceeded the severity of regulatory compliance and consumer-focussed vehicle rating programs used world-wide.

This report describes the test methodology for the paired test program, presents the results of the crash tests and discusses the implications of the findings with respect to possible countermeasures.

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TEST MEHODOLOGY

Test Vehicles:

- | | | |
|-----------------------|-----------------------|--------------------|
| 1. 2011 FORD E350 van | 15-passenger capacity | test mass: 3382 kg |
| 2. 2011 GIRARDIN MFAB | 12-passenger capacity | test mass: 3642 kg |

Striking (Bullet) Vehicles:

- | | |
|------------------|---------------------|
| 1. 2009Ford F150 | test mass: 2814 kg |
| 2. 2009Ford F150 | test mass : 2813 kg |

Crash Configuration:

The crash configuration consisted of a perpendicular impact (90 degrees) into the stationary test vehicle. Two identical Ford F150 pick-up trucks were used as bullet vehicles to strike the side of the stationary E350 van and the stationary Girardin MFAB at a speed of 75 km/h. The center of the front bumper of the Ford F150 was aligned to strike the left rear axle (driver side) of the E350, as shown in Figure 1 a & c; and the left rear axle (driver side) of the MFAB, shown in Figure 1 b & d. The impact points were selected to ensure comparable impact characteristics.



Figure 1. Test configuration for the paired comparison side impact test.

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Crash Test Dummies and Placement In Test Vehicles:

A total of seven anthropomorphic test dummies (dummies) were seated and restrained by the available seat belts in each of the test vehicles. The types of dummies were as follows:

1. WS 50th RibEye: Mid-size male with multipoint optical chest deflection measurements;
2. WS 50th IRTRACC: Mid-size male with uni-axial chest deflection measurements;
3. ES2re: Mid-size male with uni-axial chest deflection measurements;
4. WS 5th IRTRACC: Small female with uni-axial chest deflection measurements;
5. WS 5th IRTRACC: Small female with uni-axial chest deflection measurements;
6. SIDIIS RibEye: Small female with multipoint optical chest deflection measurements;
7. SIDIIS: Small female with uni-axial chest deflection measurements;

The WorldSID (WS) dummies are newly developed world harmonized side impact dummies. There are 25 mid-size male (WS 50th) and only 7 small female WorldSID dummies (WS 5th) currently in use by governments and industry research programs in Asia-Pacific, Europe and North America. These dummies represent the latest state of the art technology available for side impact crashworthiness evaluation. The ES2-re and SIDIIS are the dummies that are presently used for side impact regulatory testing by the National Highway Traffic Safety Administration (NHTSA) in the United States. Seven crash test dummies were seated in each test vehicle.

The seating locations, identified in Figure 2 and Figure 3, were selected to optimize the comparison between the two test vehicle types. For example, the left side was selected as the struck side because there is a gap between the end of the bench seat and the side wall on the right side of the 15-passenger van that is not present in the MFAB. All crash test dummies were restrained with the available lap and torso belts of the respective vehicles. Due to the limited number of available dummies, the driver seat was not occupied. Occupant protection was evaluated only for the passengers seated in the rear.

The seating location for each dummy is identified in Figure 2 and Figure 3. The layout is shown in table format for illustrative purposes only and is not to scale. The 15-passenger van illustrated in Figure 2 contains four rows of bench seats equipped with three-point lap and torso belts. The three darkened columns represent spacing between the seats; the seating locations are separated by the dotted lines. The rear doors are located on the right side of the 15 passenger van adjacent to the aisle, which is represented by the darkened row, above the first three rows of bench seats.

The MFAB layout shown in Figure 3 consists of three rows of double seats equipped with three-point lap and torso belts. The darkest coloured column to the left is an upright padded barrier

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located just ahead of the front row. The shaded row passing through the center represents the aisle.

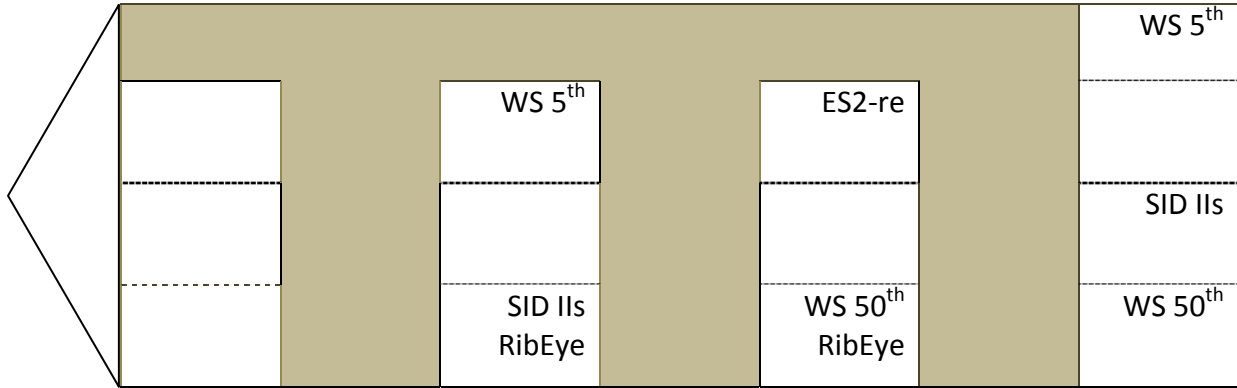


Figure 2. Occupancy in 15-passenger van (4 rows of benches)

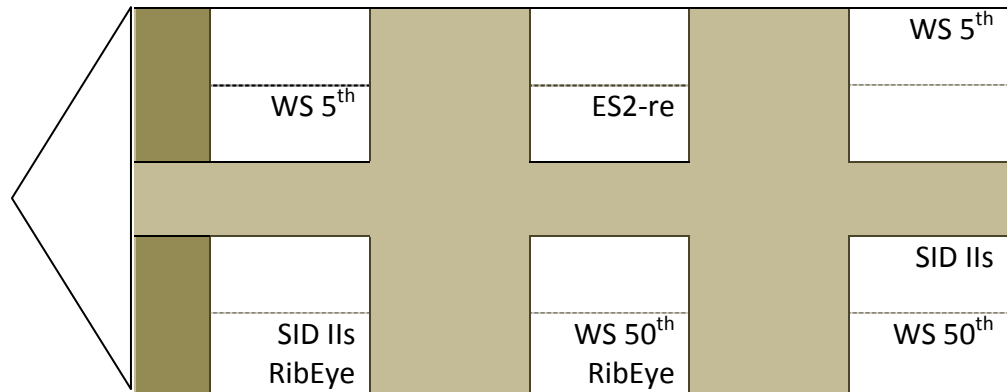


Figure 3. Occupancy in 12-passenger MFAB (3 rows of double seats)

CAMERAS and PLACEMENT:

The occupant motion and interaction with the vehicle interior and with other occupants during the crash event were recorded with six on-board high speed cameras. The frame rates for the cameras were between 500 and 1000 frames/s depending on the luminosity achieved aboard the bus. The windows in the MFAB were left open to improve interior luminosity.

The interactions between the two vehicles were recorded with six high speed cameras located on the crash pad and above the crash pad to provide multiple views of the event. Exterior high speed cameras recorded the events at 1000 frames/s. Two standard video cameras recorded the crash event in real time from two exterior views.

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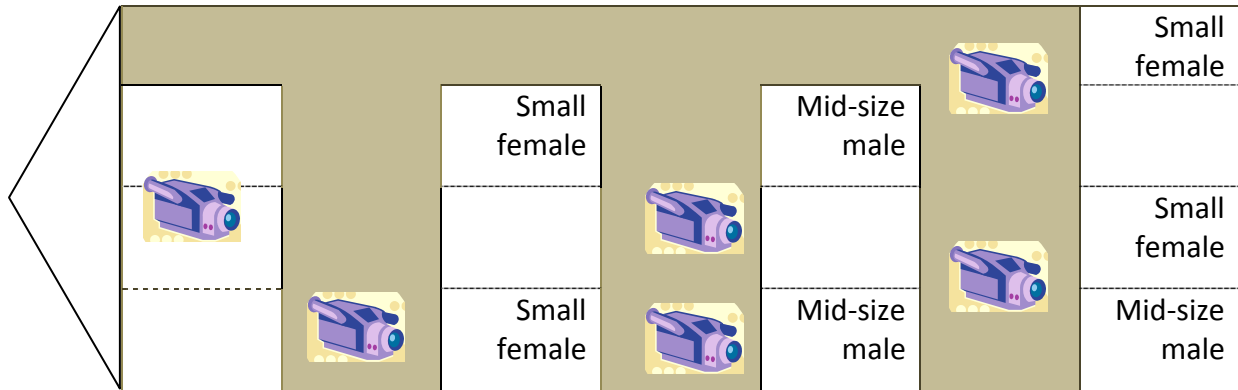


Figure 4. Approximate camera placement in 15-passenger van (6)

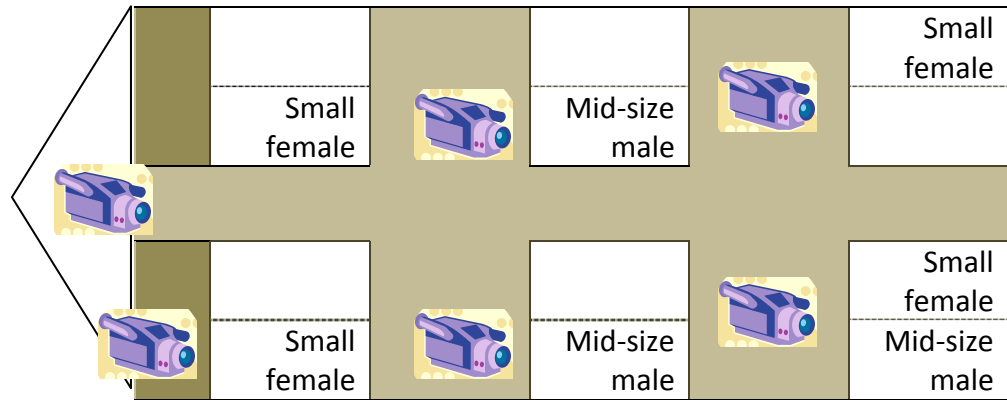


Figure 5. Approximate camera placement in 12-passenger MFAB (6)

Instrumentation

Tri-axial accelerometers were installed at the approximate center of gravity of the test vehicles. All crash test dummies were instrumented with accelerometers in the head, chest and pelvis, and load cells in the neck, lower spine and pelvis. Two of the WS dummies were equipped with rotational accelerometers in the head. In addition to the standard dummy instrumentation, an optical multi-point chest deflection sensing device (RibEye) was installed in one small female dummy (SID IIs) and in one average size male dummy (WS 50th). The processing of the data was carried out following the protocols established by the Society of Automotive Engineers (SAE J-211).

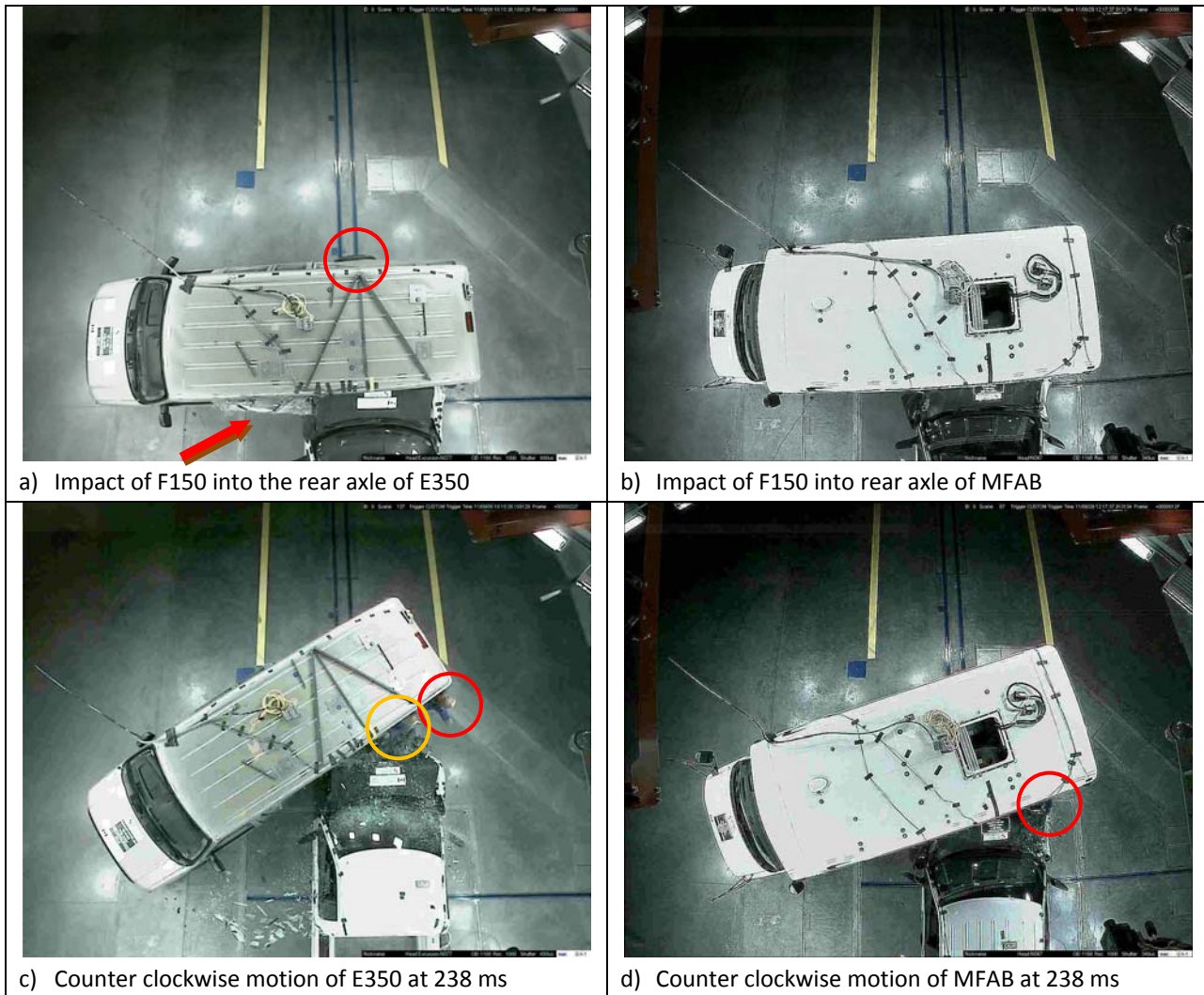
The positions of the dummy heads were recorded by using a 3-D Faro arm. The point of origin for all measurements was located at the center of the front bumper at ground level for each of the E350 and the MFAB. Head target locations were recorded for the passengers in both vehicles. Hip targets were not obtained in the MFAB due to space and restraint constraints. The hip locations in the MFAB were estimated on the basis of dummy posture.

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RESULTS

Vehicle Kinematics

The F150 bullet vehicles struck the designated impact point above the left rear axle of the E350 at a speed of 75.36 km/h and above the left rear axle of the MFAB at a speed of 75.6 km/h. Figure 6, shows freeze frames obtained from the high speed videos to illustrate the motion of each vehicle. In Figure 6a the bullet vehicle has impacted the side structure of the E350. The front end of the pick-up has deformed and is pushing the van along its path towards the top of the image. The arrow points to the side windows of the van as they are being blown out and the circle identifies the right rear wheel that is being displaced outward. In Figure 6b the MFAB is also being pushed along the path of the bullet vehicle but the windows are still intact and the right rear wheel is not visible. Both the E350 and MFAB remained engaged with the bullet vehicle for a distance of several meters prior to rotating counter-clockwise, out of the path of the bullet vehicle (Figure 6 c & d).



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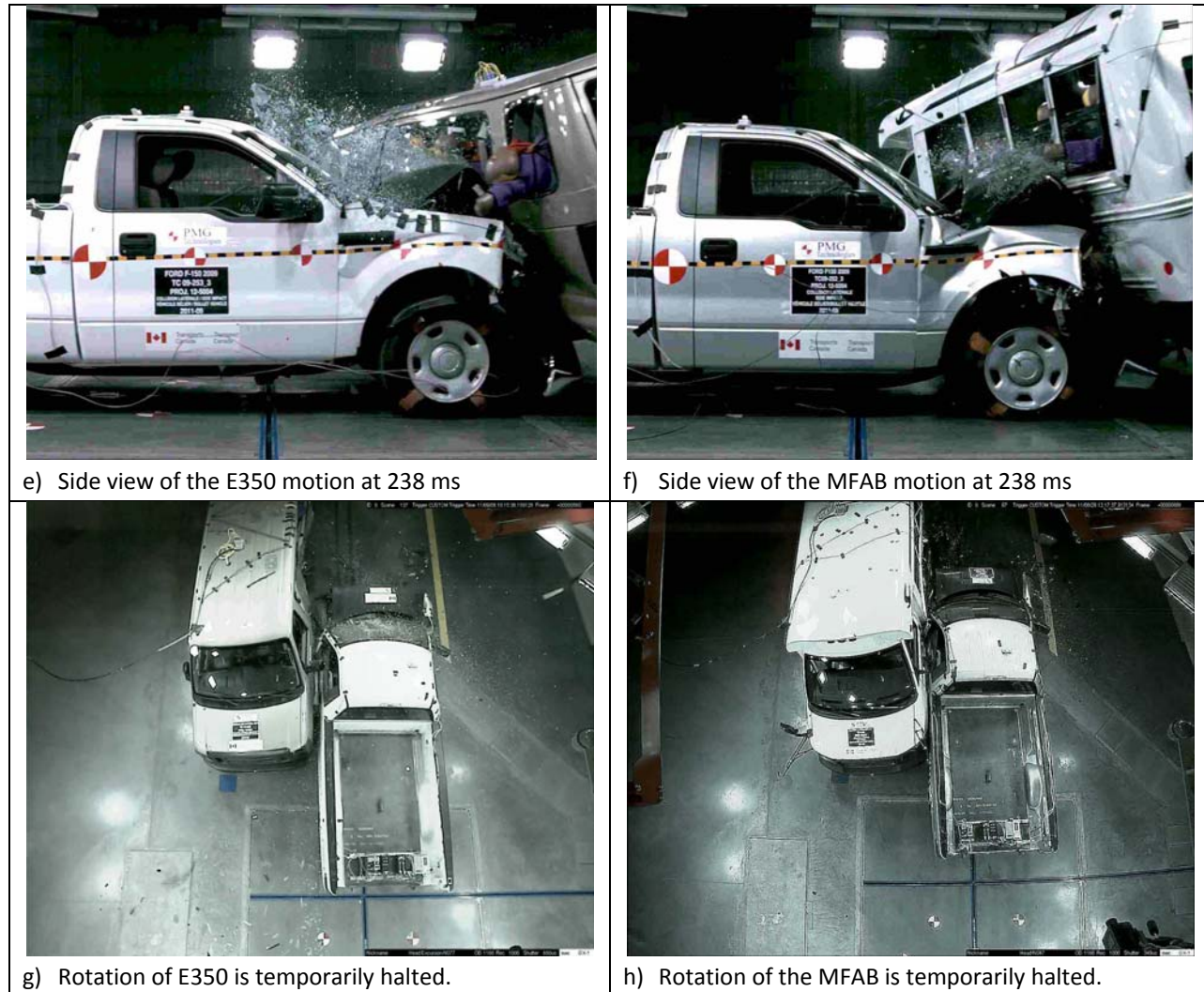


Figure 6. Sequence of motion of the test and bullet vehicles recorded by high speed video cameras.

Figure 6c is a freeze frame obtained as the E350 begins to rotate away from the path of the pick-up truck. The red circle identifies the ejection of the head and upper torso of the WS male dummy that was seated in the rearmost row on the struck side of the van. The orange circle highlights the ejection of the head and left shoulder of the WS RibEye dummy seated in the middle row on the struck side of the van. Figure 6d is a freeze frame of the MFAB obtained at the same moment in time as that shown in 6c. The red circle indicates the location where the dummy arm was ejected through the window. Figure 6e and 6f present the side view of the motion at the same instant in time shown in Figure 6c and d. Both the E350 and the MFAB tip towards the respective bullet vehicle.

The counter clockwise motion is temporarily interrupted by the body of the pick-up truck. The two vehicles become aligned along their longitudinal axis (Figure 6g & h). Each test vehicle continues its rotation to the final resting point as the bullet continues its forward trajectory.

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The accelerometers mounted to the center of gravity of each test vehicle recorded similar peak lateral accelerations. The top graph shown in Figure 7a shows that the peak lateral acceleration for the E350 shown in blue was 24.7 g occurring at 35.1 ms while the peak lateral acceleration for the MFAB, shown in red was 25.6 g occurring at 33.4 ms. Both acceleration traces indicate very rapid onsets of lateral acceleration with the peaks occurring within the first 35 ms of the impact. The MFAB appears to have experienced a longer sustained lateral acceleration than the E350. Figure 7b illustrates the vertical component of the acceleration recorded at the center of gravity of the test vehicles. The MFAB shown by the red trace appears to have experienced slightly greater vertical impulse than the E350.

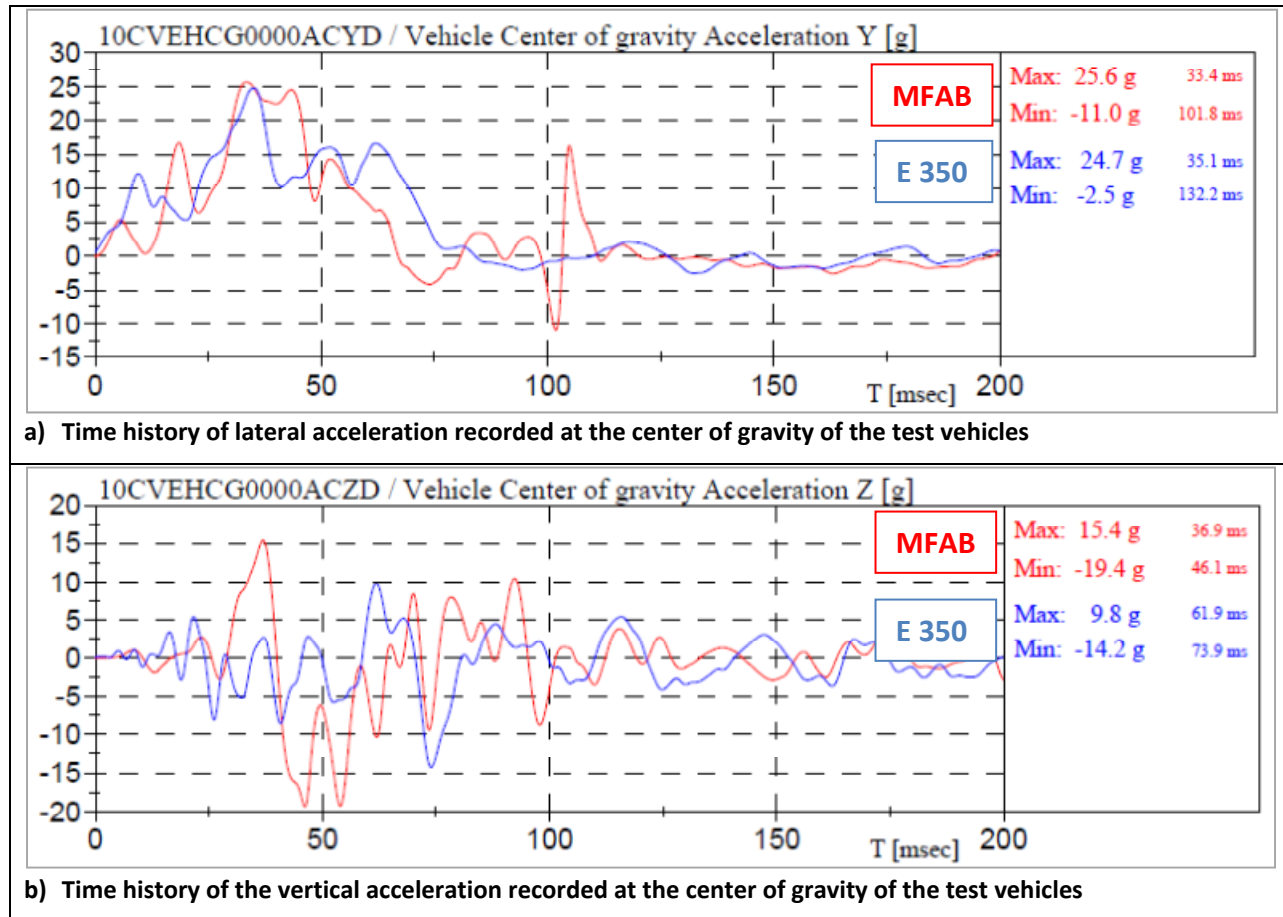


Figure 7. Time history traces of the accelerations recorded in each test vehicle.

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Vehicle Intrusion

Figure 8 and 9 present the location of the impact point and the intrusion that resulted from the collision with the E350 and the MFAB. The intrusion was limited to the area surrounding the left rear wheels in both test vehicles. There is somewhat more deformation observed in the E350 than in the MFAB.

Note that the height of the window openings is similar in both the E350 and the MFAB. Two principal differences are the sizes of the window openings and the frames. The E350 windows, located over the wheel are wider than in the MFAB and cannot be opened. The windows in the MFAB consist of two sections that slide vertically to open. The window edge acts as a cross member that extends horizontally across each window. The effect that these window designs have on occupant kinematics will be discussed in the section describing the results of the occupant kinematics.



Figure 8. Location of impact point and view of imprint left by the F150 on the E350 (left) and MFAB (right).

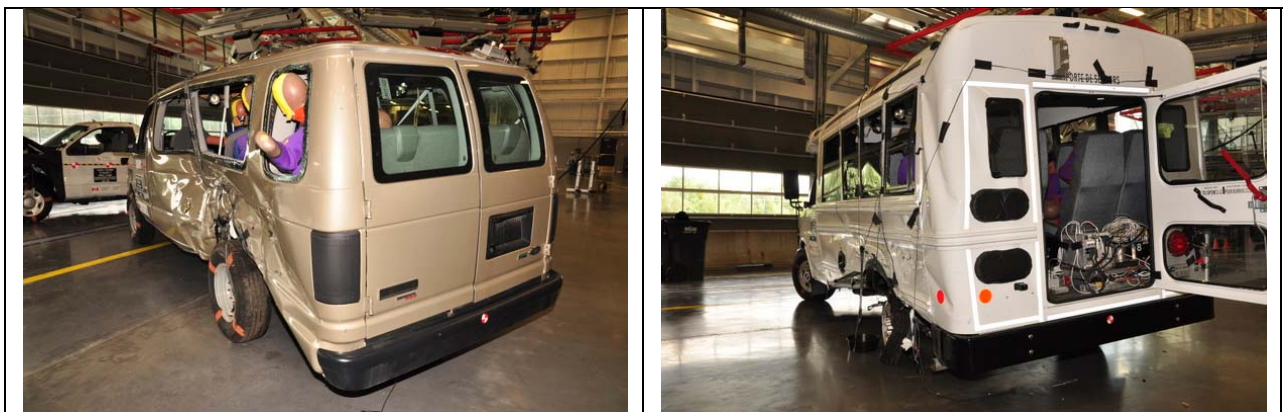


Figure 9. Oblique view of intrusion observed after the tests for the E350 (left) and MFAB (right).

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Occupant Kinematics

There were seven crash test dummies restrained with the vehicle seat belts in each test vehicle. Three dummies were seated on the struck side, three dummies were seated on the non-struck side and one was seated in the rearmost row adjacent to the struck side occupant. Figure 10 displays the interior photos taken from the front of the E350 and MFAB prior to the crash tests.

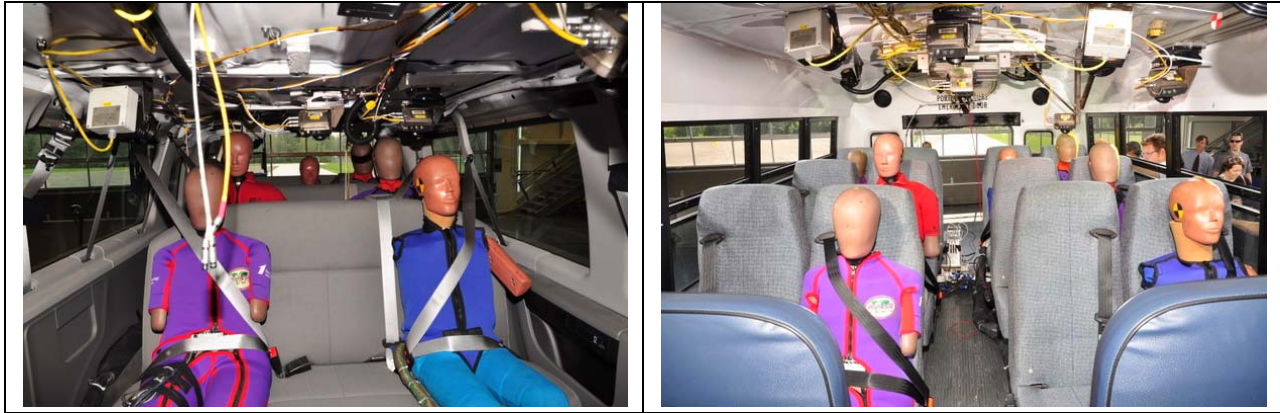


Figure 10. Occupant seating in the E350 and MFAB prior to the crash tests.

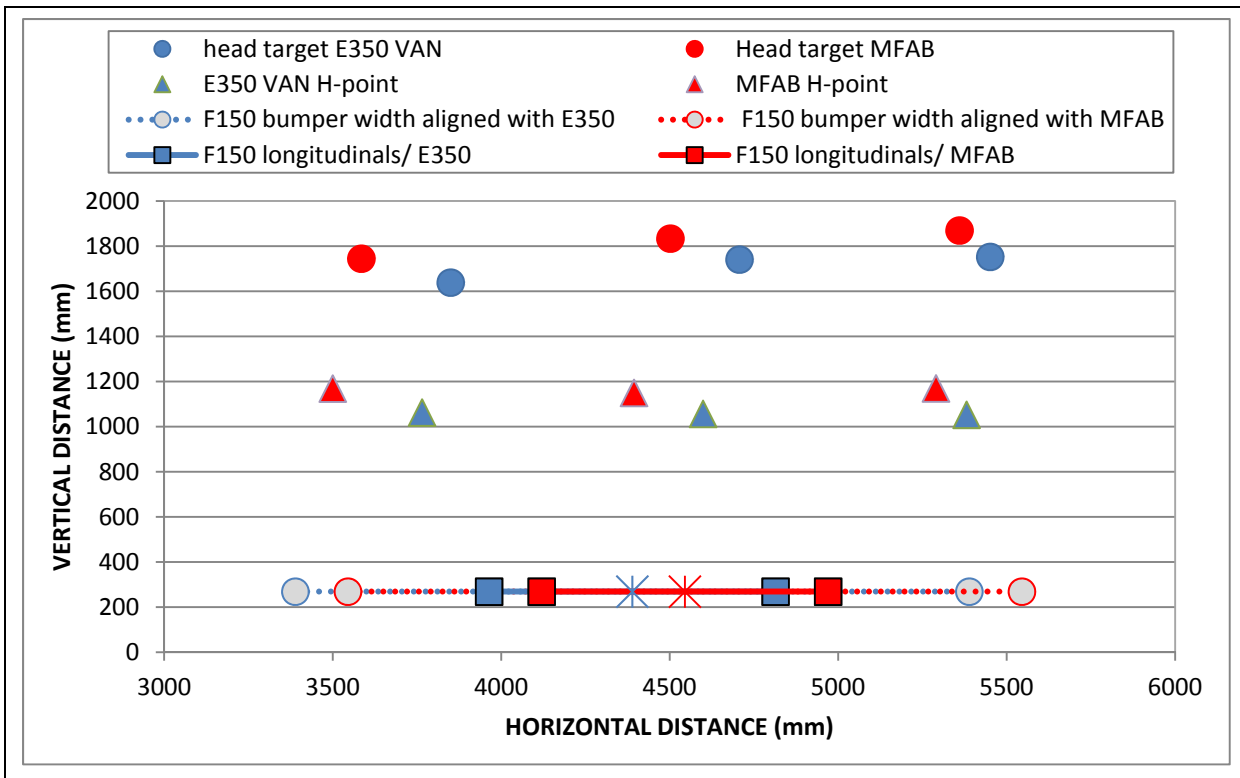


Figure 11. Relative positions of the head and hip targets of the struck side occupants with respect to bullet vehicle impact for the E350 van and MFAB.

Figure 11 is a plot documenting the dummy head and hip locations relative to the bullet vehicles. The head and hip target locations for the occupants seated on the struck side of the E350 van are represented by the solid blue circles and solid blue triangles respectively and

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represent actual measurements. The solid red circles are measured values for the head targets of the struck side occupants in the MFAB, while the red triangles are estimates of the hip point locations. The coordinates located at the bottom of the graph represent the relative location of the impacting bullet vehicles. The two blue outlined circles refer to the outer limits of the F150 bumper that struck the E350 whilst the two red outlined circles refer to the outer limits of the F150 bumper that struck the MFAB. The blue and red squares refer to the locations of the F150 longitudinal members of the E350 and MFAB, respectively. The stars refer to the center points of each striking F150 bumper.

Generally, the dummy placement in the MFAB was more spread out than in the E350. The dummies in the MFAB are seated further forward relative to the front end of the F150 when compared to the relative positions of the dummies in the E350. The struck side dummies seated in the MFAB were located further forward than the dummies seated in the E350 with the greatest difference being observed between the two foremost occupants. In fact, the head of the foremost occupant in the MFAB was located approximately 535 mm forward of the closest striking longitudinal whereas the head of the dummy seated in the E350 was only 114 mm forward of the striking longitudinal. The distance between dummy occupants of the same row was also greater in the MFAB. For example, the distance between the head targets were on average, 500mm greater in the MFAB than in the E350.

The interior profiles of the struck side walls were different in the E350 and the MFAB. Figure 12 is a front view of the occupant seated in the second row. The E350 has a stepped interior plastic trim which extends to the upper chest, below the axilla (under arm) of the 50th male dummy; the MFAB has no interior trim; the flat wall extends to the lower window frame. In the left side photo of Figure 12, there is a gap between the shoulder and the window in the E350 whereas the dummy shoulder is in full contact with the window of the MFAB seen in the right side photo. The upper belt anchors are mounted in the pillar of the E350 but integrated in the seat of the MFAB.



Figure 12. Comparison of interior trim and seatbelt anchorages in the E350 (left) and MFAB (right).

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The motion of the dummies will be described by presenting a sequence of two video images captured at the moment of impact and approximately 100 ms later in the crash event. The two images are shown for the E350 on the left and for the MFAB on the right, for each row of occupants. The images begin with the front row and progress rearward in Figure 13 through Figure 16. Descriptions of the observed motion follow each figure.

Front row kinematics:

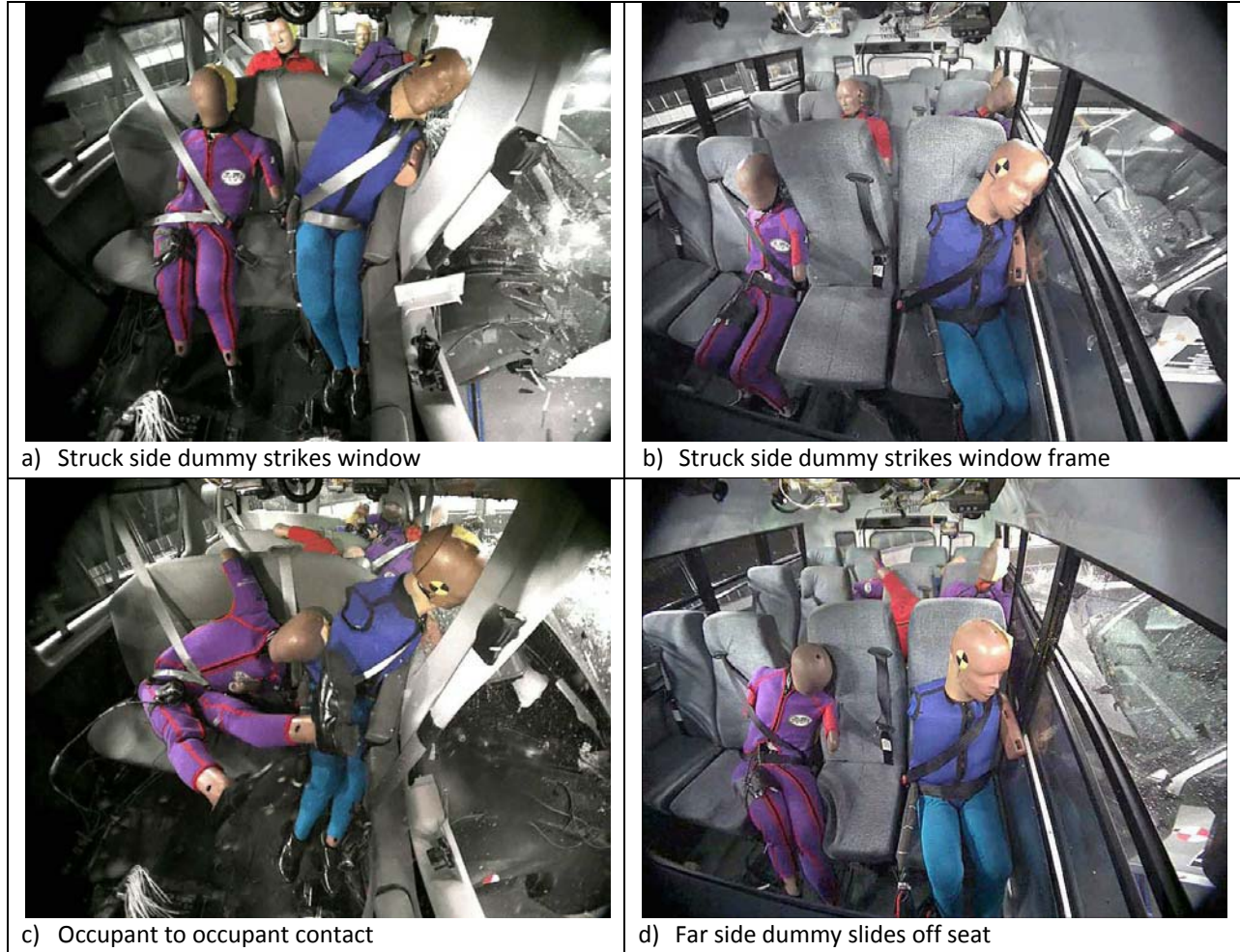


Figure 13. Motion during the crash of front row occupants seated in the E350 (left) and MFAB (right)

The front row contained two dummies representing small women, struck side SID IIs, non-struck side WS 5th. The head of the struck side dummy in the E350 shown in Figure 13 a and c first strikes the window then rolls forward from left to right striking the forward pillar of the window. The thorax and pelvis are in full contact with the interior trim as the upper torso pivots about the window frame. Based on the kinematics observed, there is a potential for head and facial injuries as well as chest and pelvic injuries. Chest injuries may be compounded by the occupant to occupant contact.

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The head of the struck side dummy in the MFAB shown in Figure 13b and d strikes the window frame that is adjacent to her seating position. The shoulder and arm complex is supported by the side wall; this eliminates outward rotation and appears to reduce the contact with the thorax. The kinematics suggest a potential for head and facial injuries.

The far side dummy in the E350 is projected laterally along the bench, flexes over the seat belt and collides with the struck side occupant. The seat belt migrates and penetrates into the abdominal region as the WS 5th dummy head impacts the struck side dummy. There is potential for serious abdominal injury and lower rib fractures from interaction with the seat belt. There may also be potential for head injury resulting from the collision with the other occupant.

The far side dummy in the MFAB is projected laterally, off the seat and is suspended by the seat belt. There is potential for serious abdominal injury and lower rib fractures from interaction with the seat belt.

Second row kinematics:



Figure 14. Motion during the crash of the second row occupants seated in the E350 (left) and MFAB (right)

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Two dummies representing average sized men are seated in the second or middle row. On the struck side is the WS 50th, on the far or non-struck side is the ES-2re. In the E350, the head of the WS 50th is ejected through the window and strikes the crumpled hood of the F150. The lettering that is seen beneath the dummy head in Figure 14a is the PMG Technologies label affixed to the hood closest to the windshield (see Figure 6a). The shoulder belt is twisting and penetrating into the neck. The shoulder appears to be lodged between the crumpling hood and the window frame of the van, while the thorax is in full contact with the trim and deforming side panel. The kinematics of the WS 50th suggest a high risk of head and facial injuries. Chest injuries in the form of multiple rib fractures possibly accompanied by internal organ trauma are likely. Chest and organ injuries would be compounded by the occupant to occupant interaction.

The head of the WS 50th in the MFAB strikes the window frame. This rigid structure prevents the ejection of the dummy head. The shoulder belt penetrates into the neck region. The shoulder is supported by the window and thus appears to act as a blocker preventing direct impact to the thorax. The right side of the WS 50th is struck by the head of the far side occupant. There is potential for head injury caused by the impact with the window frame. Chest and internal organ trauma may result from the impact with the other occupant.

The ES-2re located on the non-struck side of the E350 van is projected laterally into the struck side passenger. The dummy slips out of the shoulder belt early in the event and pivots about the lap and shoulder belt. The seat belt penetrates into the abdominal cavity while the head collides with the lower thorax of the WS 50th. The flesh skin of the dummy is dislodged. Expected injuries resulting from the observed kinematics include head injury, rib fractures and internal organ injury.

The ES-2re seated in the MFAB displays similar kinematics. The dummy translates laterally, off the seat then rotates about the seat belt and strikes the WS 50th with his head. The lap and shoulder belt penetrates deeply between the pelvis and lower ribs. Expected injuries resulting from the observed kinematics would include head injury, rib fractures and internal organ injury. The final positions of the ES2-re in the E350 van and the MFAB, as shown in Figure 15 are quite similar.

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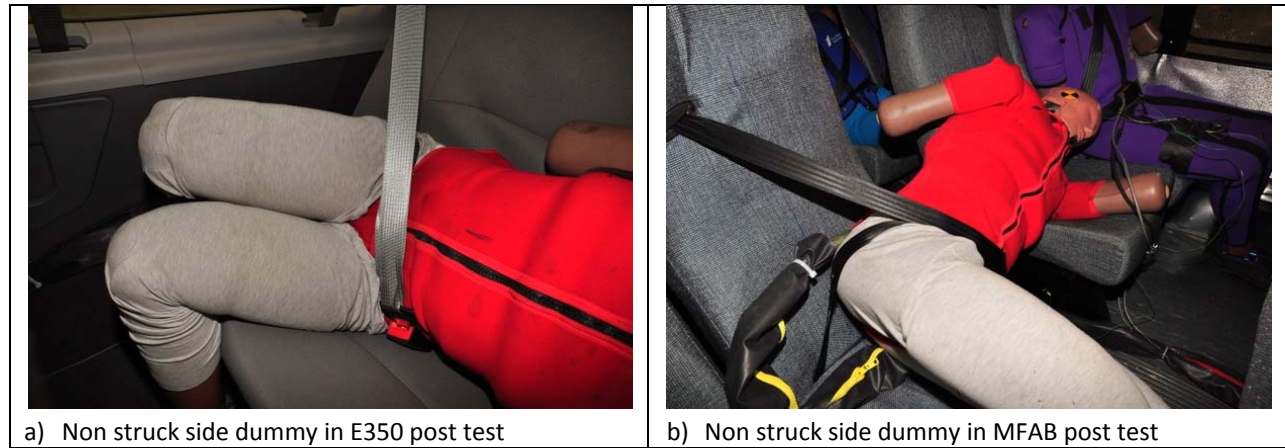


Figure 15. Photos of final resting position of the ES2-re dummy following the test.

Third row kinematics:

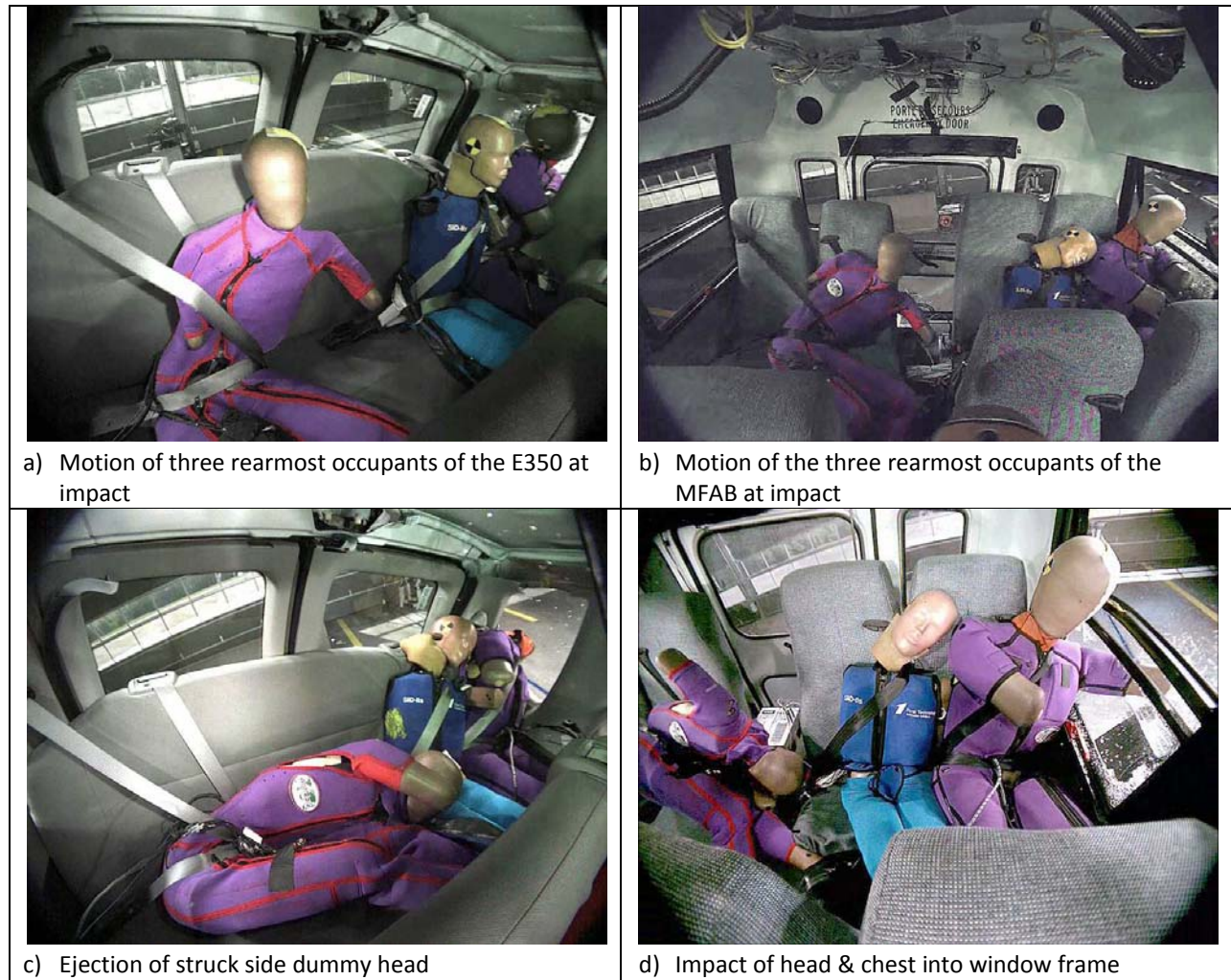


Figure 16. Motion during the crash of the rear most row occupants seated in the E350 (left) and MFAB (right)

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Three dummies representing one average sized male and two small women were positioned in the final row. The SID IIs shown in blue was adjacent to the struck side WS 50th. The WS 5th was seated in right outboard position on the non-struck side.

At impact, the head of the WS 50th seated on the struck side of the E350 is projected into the rear window. As can be seen in the upper right corner of the image in Figure 16a, the head of the WS 50th strikes the upper window edge as it is ejected through the back window. The dummy pivots about the bottom window edge, such that both the head and left shoulder are outside the vehicle. The head can also be seen from the exterior. The red circle in Figure 6c highlights the ejected head as the vehicle began its counter clockwise rotation. The shoulder belt, while taut against the neck is ineffective at restraining the upper torso. The chest makes full contact with the interior trim and side structure of the van. This can be better visualized in the post test photos shown in Figure 17. The kinematics of this occupant suggest that there is a high risk of head injury, risk of laceration to the head and neck as well as an elevated risk of organ trauma, chest and upper extremity injury.

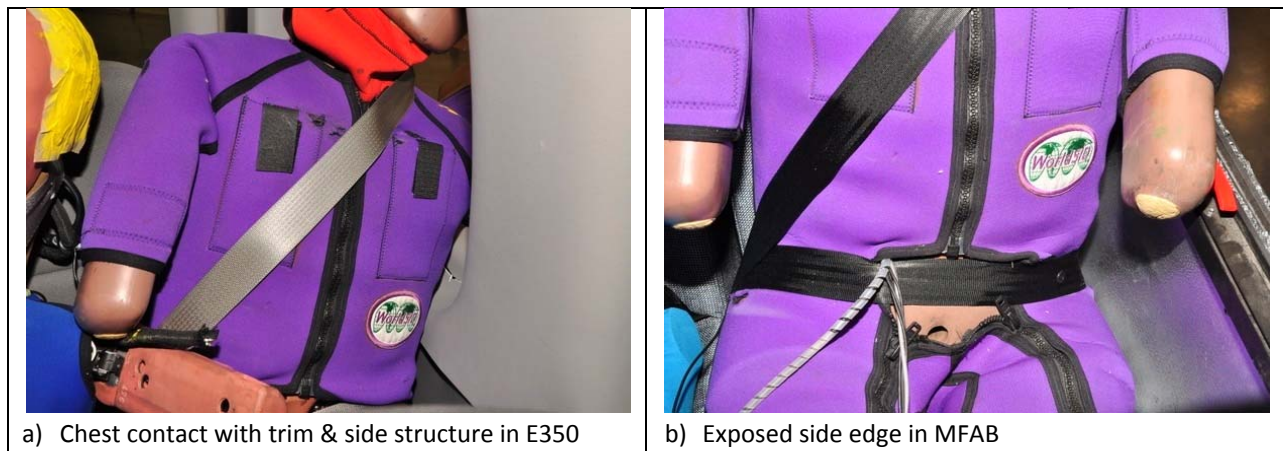


Figure 17. Photos taken after the crash of the rearmost struck side dummy chest and side structures.

The head of the WS 50th seated in the MFAB struck the window frame cross member at impact as shown in Figure 16b. In Figure 16d one can observe the distortion of the window frame and the impact of the dummy shoulder and arm shattering the windows. Contact was observed between the chest of the dummy and the lower edge of the window. Impact occurred at an angle. The standard two dimensional dummy rib instrumentation contained in this version of the WS50th cannot deflect in this direction. As can be seen in Figure 17b above, the bottom edge of the window in the MFAB is unprotected and contains a handle to release the window in emergency situations. The kinematics for this occupant indicate that there would be a risk of head injury, a risk of head and/or neck lacerations and a possibility of chest and or organ trauma. Upper extremity injuries involving fractures and/ or lacerations to the arm and shoulder may occur.

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The adjacent occupant seated in the E350 collides with the struck side occupant and is struck by the far side occupant. There is a rather severe impact between the head of the far side female and the chest of the SIDII. Witness marks, identified by the yellow smear on the blue jacket are seen in Figure 16c. The injury risk for this dummy may include the head and would very likely involve the chest.

The adjacent occupant seated in the MFAB collides with the struck side occupant but is not struck by the far side occupant. The SIDII appears to be shielded from the impact forces by the larger dummy seated on the struck side. There may be a risk of head injury from contact with the struck side occupant.

In both the E350 and the MFAB the far side occupant is not effectively restrained by the lap and shoulder belt. In both crashes the dummy is observed to slip out of the belt as she is projected towards the impact zone. The dummy rotates about the seat belt striking the chest of the SIDII in the case of the E350. If one looks closely at the images in Figure 16 c & d it is possible to observe the extreme penetration of the seat belt into the abdominal cavity. In fact, the two crash tests severed the dummy lower spine. In the MFAB she cannot reach the SIDII but essentially ends up with her head on the floor between the seats as shown in the post test photos below in Figure 18. In both vehicles there is high risk of head injury, a high risk of chest fractures and internal organ injury as well as a potential for lower spine injuries.

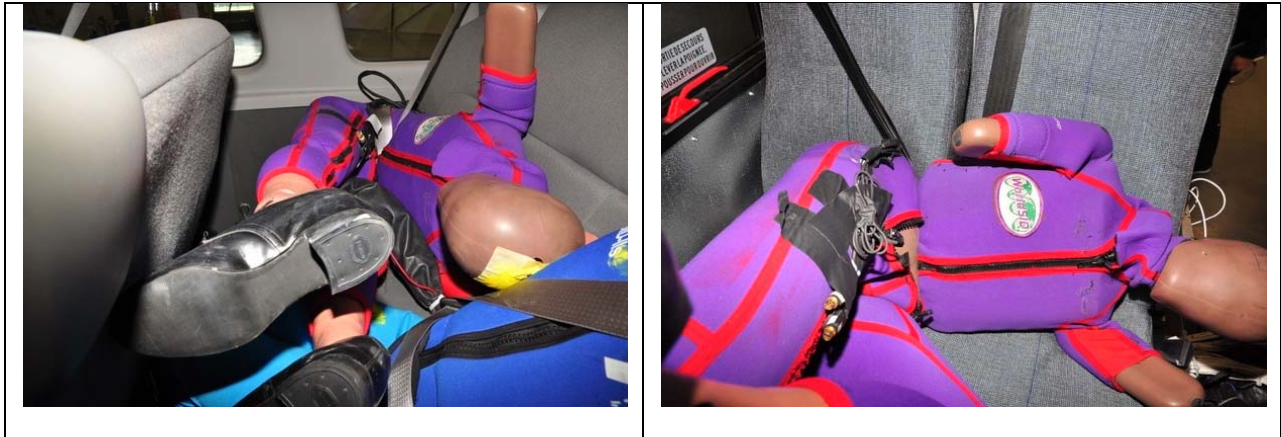


Figure 18 Photos of final resting position of far side dummy seated in rear row of E350 (left) and MFAB (right).

Table 1 presents a summary of the potential for injury for each occupant that is based on the kinematic analysis presented. It is important to note that the kinematic analysis cannot be used to quantify the degree of risk. For example, in the case of a head impact we recognize that there is a risk of injury but we cannot for example, readily discriminate between a 10% risk of serious injury and a 50% risk of serious injury. The red shaded boxes in the table serve as flags to signal the potential for injury. Based on this initial overview the injury potential appears to be comparable for both vehicles.

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The next step is to use this analysis in conjunction with injury response measures recorded by the on-board dummy instrumentation to confirm the validity of measured responses and define the risks. Since even the latest state-of-the-art dummies cannot detect all sources of injury we rely on available measures, the kinematic response and best engineering judgement to determine a comprehensive assessment of protection.

Table 1. Summary of injury potential based on kinematic analysis

	STRUCK SIDE				NON-STRUCK SIDE			
LOCATION	DUMMY	BODY REGION	E350	MFAB	DUMMY	BODY REGION	E350	MFAB
ROW 1	SIDiIs	HEAD			WS 5 th	HEAD		
		NECK				NECK		
		CHEST	*			CHEST		
		ORGAN				ORGAN		
		UPPER EXT.				UPPER EXT.		
		SPINE				SPINE		
		LACERATION	facial	facial		LACERATION		
ROW 2	WS 50 th	HEAD	ejection		ES2-re	HEAD		
		NECK	ejection			NECK		
		CHEST	*	*		CHEST		
		ORGAN	*	*		ORGAN		
		UPPER EXT.				UPPER EXT.		
		SPINE				SPINE		
		LACERATION	facial	head		LACERATION		
ROW 3	WS 50 th	HEAD	ejection		SIDiIs	HEAD		
		NECK	ejection			NECK		
		CHEST				CHEST	*	
		ORGAN				ORGAN	*	
		UPPER EXT.				UPPER EXT.		
		SPINE				SPINE		
		LACERATION	face/ neck	head/ neck		LACERATION		
					WS 5 th	HEAD		
	LEGEND					NECK		
	IMPACT with interior of vehicle					CHEST		
	EJECTION from window					ORGAN		
	IMPACT with adjacent occupant					UPPER EXT.		
	CONTACT with exposed surface					SPINE		
STRUCK by far side occupant				LACERATION				

PAIRED CRASH TESTING of a 15 PASSENGER VAN & MFAB

Injury Measures

Injury risk is estimated by comparing measured values obtained from the dummy instrumentation to established injury reference values or injury risk curves. Injury reference values are generally developed by subjecting a small number of cadavers to prescribed test conditions and comparing the measured responses to those of a dummy exposed to the same test conditions. Since cadaver data are rare and costly to obtain, the data are quite limited. Injury reference values are available only for certain body regions and are valid for only a limited number of injury mechanisms. The resulting estimate of risk remains just that, an estimate with a wide margin of error.

The current regulatory dummies, ES2-re and SIDII have established injury reference values for the body regions that are mandated by the regulation, for example the head, chest and pelvis. The newly created WorldSID 50th has *proposed* values for the head, neck, chest, pelvis and legs, though the statistical methods used to define the risk curves have yet to be finalized. The injury reference values for the WS 5th have not been developed, so while an estimate of risk cannot be established at this time, it is nevertheless possible, to compare responses and evaluate the relative severity of an impact.

A final note of caution is offered on the orientation of the instrumentation within the dummies. With the possible exception of multi-axial accelerometers most sensors in a dummy are designed and aligned to measure in the most likely direction of impact. Since a side impact dummy is almost always seated upright in a test vehicle the sensors are calibrated to measure perpendicular impacts. The capability to measure oblique loading is not possible in either the ES2-re or the SIDII due to the mechanical design of the ribs. The WorldSID dummies are mechanically capable but the sensors to measure oblique and other out of plane motions are still under development. Therefore, in a severe collision such as the E350 and MFAB, the direction of force may not be detectable. Specifically, there are no sensors capable of accurately tracking the impact exposure for the non-struck dummy as the dummy tumbles out of the seat towards the floor.

Table 2, summarizes the injury responses. Shaded cells represent injury responses for which there are known injury risk values. The red shaded cells refer to a nominal 25% risk of severe injury (AIS 4+), the blue shaded boxes refer to a nominal 25% risk of serious injury (AIS 3+) and the yellow boxes refer to a nominal 25% risk of a moderate injury (AIS 2+). Severity of injury is described by the Abbreviated Injury Scale (AIS) and represents the *'threat to life'* associated with the injury. Injuries are ranked from 1 to 6, where 1 is considered minor and 6 is not survivable. The scale is not a measure of disability. Therefore a moderate injury to the head which is an AIS 2 can have serious long term consequences that are not reflected in the threat to life.

PAIRED CRASH TESTING of a 15 PASSENGER VAN & MFAB

Table 2: Summary of injury measures and injury risks where applicable.

LOCATION	STRUCK SIDE				NON-STRUCK SIDE			
	DUMMY	BODY REGION	E350	MFAB	DUMMY	BODY REGION	E350	MFAB
ROW 1	SIDIIIs	HEAD peak g ¹	74	66	WS 5 th	HEAD peak g	140	70
		HIC 36	405	270		HIC 36	1793	520
		NECK force	1631	1075		NECK force	1666	1183
		THORAX Dy	46			THORAX Dy	7	41
		T ₁ g	46	27		T ₁ g	42	66
		T ₁₂ g	144 ²	31		T ₁₂ g	35	51
		PELVIS force	6080	2456		PELVIS force	463	837
		PELVIS peak g	100	27		PELVIS peak g	47	43
ROW 2	WS 50 th	HEAD peak g	77	65	ES2-re	HEAD peak g	204	144
		HIC 36	578	343		HIC 36	7524	2486
		NECK force	2908	1143		NECK force	4025	2947
		THORAX Dy				THORAX Dy		
		T ₁ g	35	28		T ₁ g	43	35
		T ₁₂ g	54	45		T ₁₂ g	44	53
		PELVIS force	1745	880		PELVIS force	6120	4267
		PELVIS peak g	75	47		PELVIS peak g	60	73
ROW 3	WS 50 th	HEAD peak g	162	71	SIDIIIs	HEAD peak g	120	74
		HIC 36	1604	519		HIC 36	3285	678
		NECK force	3080	2282		NECK force	4168	2203
		THORAX Dy	56	42		THORAX Dy		
		T ₁ g	88	40		T ₁ g	108	53
		T ₁₂ g	69	45		T ₁₂ g	322 ²	55
		PELVIS force	1400	974		PELVIS force	7274 ²	4175
		PELVIS peak g	104	48*		PELVIS peak g	81	50
			LEGEND		WS 5 th	HEAD peak g	115	75
			SEVERE			HIC 36	>2000	974
			SERIOUS			NECK force	5427	2595
			MODERATE			NECK Mx/My	36/104	44/33
			5% Moderate	*		THORAX Dy		
			DATA LOSS			T ₁ g	161	58
		T ₁₂ g	78	43				
		PELVIS force	DL	347				
		PELVIS peak g		54				

¹ Peak resultant head acceleration 3 ms clip

² Caused by collision with other occupant

PAIRED CRASH TESTING of a 15 PASSENGER VAN & MFAB

Struck side Occupants

Front Row

The peak resultant head acceleration (3ms clip) and the head injury criterion (HIC) for the small female dummy seated in the first row were below the levels normally associated with a risk of injury to the head. The SIDII's head responses recorded in both the E350 and the MFAB were below the regulatory injury threshold levels. The chest deflection and pelvic acceleration responses for the SIDII's seated in the E350 indicate a 25% risk of moderate injury. These injuries might include for example, one or two rib fractures and a pelvic fracture. The T12 or lower spine acceleration response is indicative of a 25% risk of severe thoracic or abdominal trauma for the dummy seated in the E350 and a 25% risk of serious thoracic or abdominal trauma for the dummy seated in the MFAB. The elevated spinal accelerations were caused by the head of the far side occupant colliding with the chest of the SIDII's in both the E350 and MFAB tests.

Middle row

The peak resultant head acceleration (3ms clip) and the head injury criterion (HIC) for the mid-size male dummy seated in the second row suggest a risk of moderate injury to the head for the WS 50th seated in the E350. In the MFAB, the WS 50th head struck and deformed the window frame but was contained within the vehicle; the head injury assessment values were low.

The risk of rib fractures could not be assessed in either test vehicle due to data loss. The pelvic response of the dummy seated in the E350 suggests a risk of moderate injury or fracture to the pelvis.

Rearmost row

The peak resultant head acceleration (3ms clip) and the head injury criterion (HIC) for the mid-size male dummy seated in the third or rear most row suggest a risk of severe injury to the head for the WS 50th seated in the E350. In the MFAB, the WS 50th head struck and deformed the window frame but was contained within the vehicle; there was a risk of moderate head injury for this seating position in the MFAB.

The deflections measured in the chest suggest a risk of serious injury (three or more rib fractures) for the WS seated in the E350 and a risk of moderate injury (two or more rib fractures) for the WS seated in the MFAB. Peak resultant acceleration clips obtained at the upper (T1) and lower spine (T12) are quite elevated for the WS seated in the E350 compared to the MFAB. While no definitive risk curves have been defined this magnitude of acceleration could lead to serious thoracic or internal organ injuries. Finally, the elevated peak resultant accelerations recorded in the pelvis of the WS seated in the E350 are consistent with a risk of fracture or moderate injury.

PAIRED CRASH TESTING of a 15 PASSENGER VAN & MFAB

Far-side (non-struck) Occupants

Front Row

The peak resultant head acceleration (3ms clip) and the head injury criterion (HIC) for the small female dummy seated in the first row suggest a risk of severe head injury in the E350 and moderate injury in the MFAB.

The upper and lower spine accelerations (T1 and T12) were elevated for the WS 5th seated in the MFAB. However, since injury risk assessment thresholds have not been developed for this dummy it is not possible to estimate the likely severity of injury at this time.

Middle row

The peak resultant head acceleration (3ms clip) and the head injury criterion (HIC) for the mid-size male dummy seated in the second row suggest a risk of severe injury to the head for the ES2 re seated in the E350 and seated in the MFAB. The neck responses point to a risk of severe neck injury, possibly involving neurological injury, for the ES2re seated in the E350 and a moderate neck injury, possibly involving vertebral fracture, for the dummy seated in the MFAB.

The upper and lower spine accelerations are indicative of serious chest and or abdominal trauma for both the dummies in the E350 and MFAB. There is also a risk of moderate injury (fracture, for example) to the pelvis.

Rearmost row

The peak resultant head acceleration (3ms clip) and the head injury criterion (HIC) for the small female dummy seated in the middle seat position adjacent to the struck side male, are consistent with a risk of severe head injury in the E350 and moderate head injury in the MFAB. The neck forces recorded in the SIDIIs represent a risk of severe neck injury with neurological injury for the dummy seated in the E350 and a risk of serious neck injury also involving some neurological trauma for the dummy seated in the MFAB.

Elevated spinal accelerations and high pelvic forces resulting from impact with the adjacent dummies could cause severe thoracic and or abdominal trauma and pelvic injury for the dummy seated in the E350. While not negligible, the accelerations and pelvic forces recorded in the SIDIIs seated in the MFAB, were nevertheless below the regulatory injury threshold.

The WS5th seated in the outboard location had head responses that were consistent with a risk of severe head injury in the E350 and serious head injury in the MFAB. Since injury risk assessment thresholds have not been developed for this dummy it is not possible to estimate the likely severity of injury at this time.

DISCUSSION

Struck side Occupants

Effect of the interior trim on loading exposure and injury risk

Figure 19 compares the interior trim of the E350 van to the sidewalls of the MFAB with respect to the outboard struck side dummy profile. The two profiles are very different. The sidewalls of the E350 illustrated by the black line are covered with a plastic trim. The trim extends inboard, approximately 120 mm from the bottom of the window and forms two stepped horizontal surfaces, each approximately 60 mm wide. The lower horizontal surface or ledge appears to serve as an armrest. The window, also shown in black has a slight curvature with an upper edge that is in-line with the lower interior trim. The interior of the MFAB illustrated by the grey line is a flat wall with no interior trim. The windows are almost vertical.

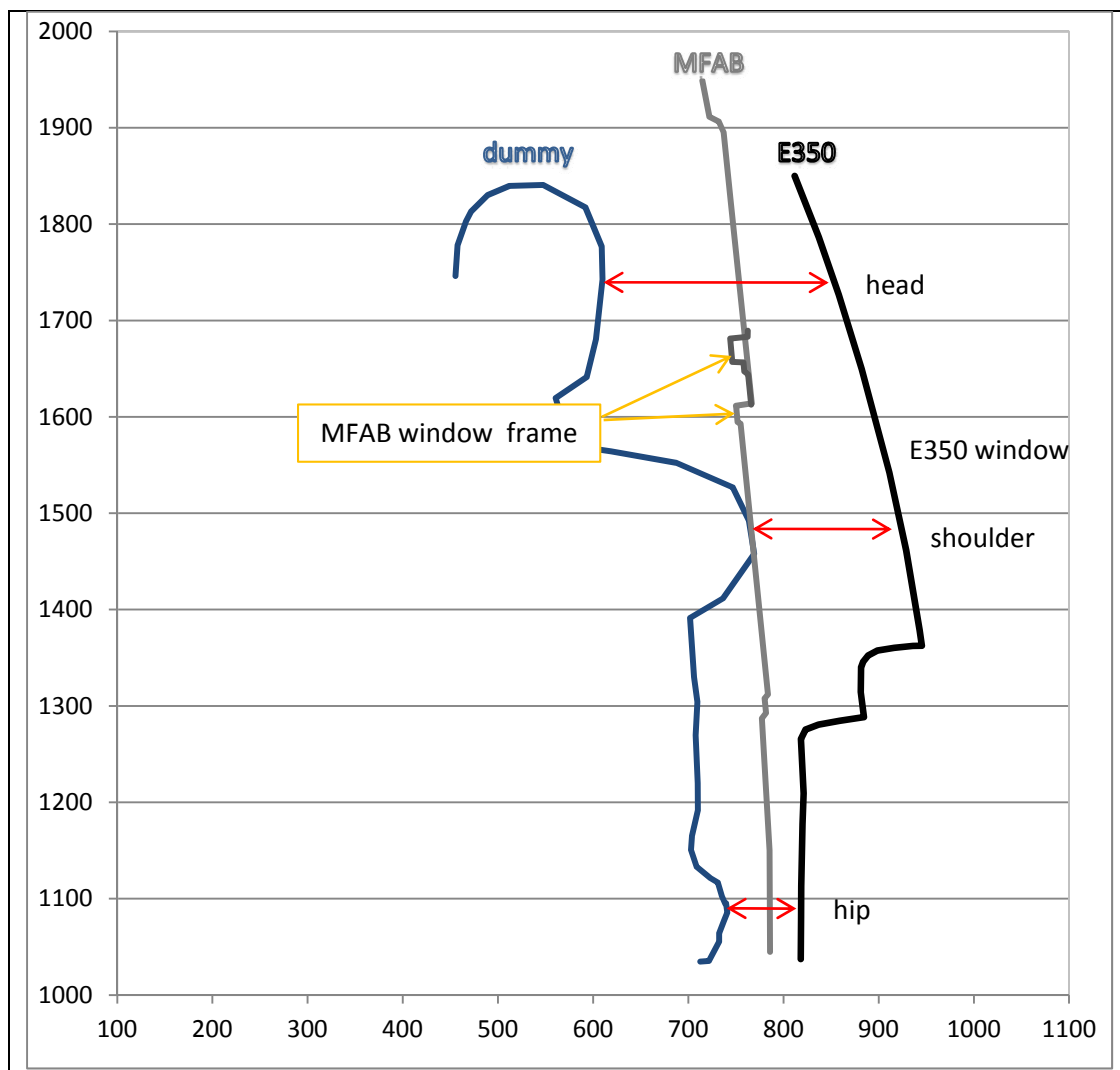


Figure 19. Profile of the interior trim and window of the E350 van (black) and the interior wall of the MFAB (grey).

PAIRED CRASH TESTING of a 15 PASSENGER VAN & MFAB

Of significance in the outline views shown above is the distance between the outboard struck side passenger, outlined in blue and the trim or sidewall of the respective vehicles. The greater the distance between an occupant and the interior surface, the greater the velocity with which the body of the occupant will impact that surface. Irregular surfaces created by some armrests or interior trims as observed for example, in the E350, can exacerbate the relative displacement of body segments and can increase the risk of injury. In the E350 the head and shoulder are projected into the triangular shaped void that is formed by the window and interior trim and shown in Figure 19. This means that the head and upper thorax can pivot about the trim. The head strikes the window with increased speed and the ribs are in direct contact with the intruding trim. In the MFAB, the kinematics are different because the flat wall surface prevents the struck side dummy from pivoting. Since the side of the dummy is already in contact with the sidewall prior to the crash, there is very little space for the dummy to accelerate. The WorldSID translates laterally compressing the shoulder, while the hips are rapidly blocked by the sidewall and the head strikes the window frame. The bony protuberance of the shoulder represented in this case by the hardware in the dummy shoulder and pelvis reduce the extent of direct contact with the ribs.

Table 3. Distances from WS 50th dummy landmarks to the sidewall as a function of vehicle

Landmarks	E350 (mm)	MFAB (mm)
head	250	140
shoulder	170	0
pelvis	75	45

It is important to note that the kinematics and associated injury risks described herein apply only to the specific crash configuration that was tested, the size (including shape) of the struck side occupants and their placement relative to the side structure. Furthermore, since the MFAB and E350 were stationary when impacted, the motion of the occupants did not take into account the effects of pre-crash motion, typically associated with avoidance manoeuvres and braking. The head of a shorter statured occupant for example, could have struck the window of the MFAB instead of the stiff frame, resulting in a shattered window and ejection of the head. A shorter occupant in the E350 may not have extended as far out of the window. Similarly, outcomes would have been different had the occupants not been seated upright. Since the window frame and pillars of the MFAB are not protected with energy absorbing material there is a risk of head injury should impact occur. The further the head travels prior to the impact the greater the velocity of impact and the graver the risk of traumatic head injury.

PAIRED CRASH TESTING of a 15 PASSENGER VAN & MFAB

A known countermeasure to optimize occupant protection and reduce the risk of head injuries, is the side curtain air bag. In the case of the E350, a curtain that could deploy from the roof rail just above the window and extend down to the trim might eliminate the triangular gap and create a cushioned wall. While it is not known how this might perform in such a severe side impact such a system can generally mitigate against ejection, reduce impact to the head and protect occupants from shattered glass. Similarly for the MFAB, while it is not known how effective a side curtain air bag may be in such a severe impact collision, an inflatable curtain can generally mitigate against ejection and reduce the severity of potential head impacts with the window frame. The addition of energy absorbing material to exposed interior structural elements of the MFAB may also reduce the severity of head strikes in less severe collisions and enhance the protection provided by an inflatable curtain

The kinematics and injury mechanisms observed in both the E350 and the MFAB are consistent with the dummy motions and responses that are observed in other passenger vehicles subjected to side impact crash testing. Side impact regulations and consumer safety rating test programs employ test speeds that are substantially less severe than the 75 km/h bullet velocity in this paired testing. For example, the American New Car Assessment Program (NCAP) and the FMVSS 214 regulation accelerate a crabbed deformable barrier at 62km/h and 54 km/h, respectively into the side of passenger vehicles. The Insurance Institute for Highway Safety (IIHS) uses a moving deformable barrier that is intended to simulate the front end of a pick-up truck. This barrier has a greater surface area and has 100mm more ground clearance than the U.S. compliance barrier. The IIHS test which has been instrumental in motivating the automotive industry to introduce head curtain technology and other side impact countermeasures employs a test speed of 50 km/h. Vehicle manufacturers have spent many years examining the effects of side structures and interior trim architecture in an effort to mitigate trauma caused by side impact collisions. The introduction of air curtain technology has proven to be possibly, the most effective countermeasure to reduce head injuries in side and rollover collisions.

Effect of seat spacing on loading exposure

The head of the foremost dummy occupant in the MFAB was located approximately 400 mm further forward of the closest striking longitudinal than the head of the dummy seated in the E350. This means that for this specific crash configuration, an occupant seated in the first row would have been further from the impact region in the MFAB than in the E350 and exposure to collision forces would have been somewhat less severe. The difference in spacing of the center and rear seats between the two vehicles was not as great as for the front row seat.

PAIRED CRASH TESTING of a 15 PASSENGER VAN & MFAB

Non-Struck side Occupants

All dummies seated on the non-struck side of both the E350 and the MFAB had head impacts that were consistent with moderate to severe head injuries. In both vehicles the three point belts were ineffective in restraining the upper torso. In each of the three rows the force from the impact caused the small female WorldSID 5th and the larger ES2 re representative of a mid-sized male to pivot about the lap portion of the three point belt.

In the E350 the non-struck side dummies were projected across the bench seat. The heads of all three dummies collided with the dummy seated on the struck side of the bench. In the rearmost row the WS 5th collided with the SIDs seated adjacent to the WS 50th. The lap portion of the seat belts penetrated each of the dummy abdomens. In the case of the WS 5th seated in the rearmost row the belt loads combined with the motion of the dummy were severe enough to tear the lower spine. Since this dummy had been subjected to similar loads in the MFAB test it may be that some pre-existing damage contributed to the severing of the lower spine.

In the MFAB the non-struck side dummies were projected across the centre aisle. The heads of the two small female WS 5th dummies struck the seat that was located in the same row but across the aisle. The spacing between the small female and struck side dummies was large enough in the MFAB to prevent dummy to dummy contact. The head of the ES 2re collided with the WS 50th dummy seated on the struck side of the row. As in the E350 the shoulder portion of the three-point seat belt failed to restrain the upper torso and each dummy pivoted about the lap belt towards the aisle. The pelvis of the WS 5th seated inboard in the front row slid into the aisle as the dummy abdomen and pelvis were restrained by the seat belt. The WS 5th seated outboard in the rear most row slid across the inboard seat and was pitched head first into the aisle. In all cases penetration of the seat belt into the abdominal region was observed.

Since the dummies are not designed to measure responses from such severe out of plane motion it is not possible to quantify the risk of injury on the basis of dummy response. For instance, there is to date, no instrument capable of measuring or indeed detecting the extent of belt intrusion into the abdominal cavity. Based on visual analysis of the videos there would be a strong likelihood of severe abdominal injury including liver, spleen and bowel contusions and lacerations. Lower rib fractures and serious spinal trauma could not be ruled out for any of the non-struck side occupants in either the E350 or the MFAB.

The protection of non-struck side occupants is a challenge in all passenger vehicles involved in side impact crashes. The problem is by no means unique to either 15-passenger vans or buses. Until very recently attention has focussed almost exclusively on the protection of struck side occupants. In fact current world regulations and consumer programs such as NCAP and IIHS for side impact protection include only struck side occupants. As a result, there has been

PAIRED CRASH TESTING of a 15 PASSENGER VAN & MFAB

comparatively little emphasis directed towards the development of countermeasures. Certain manufacturers are introducing or exploring the feasibility of side airbags that would deploy in the centre of the vehicle, between two occupants, while others are investigating the role of belt pretensioners and seat designs. Clearly, in severe side impact crashes the challenges of occupant protection are so great that they will likely require a comprehensive multi-system approach that combines structural, seat and restraint designs as well as supplementary restraint systems, quite possibly in the form of side airbag technology.

CONCLUSION

A paired crash test program was conducted, to compare the protection available to restrained occupants of a 15-passenger van to that available to restrained occupants in an MFAB in a severe side impact crash test. A model year 2011, Girardin multi-functional activity bus (MFAB) and a model year 2011 Ford E350 15-passenger van were each impacted at 90 degrees in the left rear axle by a model year 2009 Ford F150 travelling at 75 km/h.

Two of the three crash test dummies seated on the struck side of the E350 were partially ejected through the shattered window. Based on the injury responses obtained from the WorldSID 50th dummies seated at these locations it is anticipated that a human occupant exposed to the same conditions as this test configuration would have had a risk of moderate to severe head injury and moderate to serious chest and abdominal trauma. The arm of the rear most WorldSID 50th positioned on the struck side of the MFAB was ejected. The motion of the head was stopped by the window frame for all three dummies seated on the struck side of the MFAB. There was a risk of moderate head injury for the rear most struck side occupant. The small female dummy seated in the front row of the E350 had responses that were consistent with a risk of severe abdominal injury, which was exacerbated by an impact from the far side dummy seated in the same row; and a risk of moderate chest and pelvic injuries caused by contact with the interior trim. The same occupant in the MFAB demonstrated a risk of serious injury to the abdomen from contact with the sidewall of the bus. The injury measures for the occupants of the MFAB were less severe than for the E350 because of their close proximity to the flat wall surface of the interior sidewall. A difference in initial occupant position in the MFAB whereby the occupant would be seated further in-board, slouched on the seat or leaning inboard would likely increase the risk of injury.

The lap and shoulder belts in both the E350 and the MFAB were ineffective at restraining the upper torso of all the non-struck side occupants. The closer proximity of the small female occupants seated in the same row contributed to more severe risks of head and neck injuries in the E350. The ES-2re and WorldSID dummies seated in the second row did collide. For the mid-size male dummies seated on the non-struck side of both the MFAB and the E350 there was a risk of severe head injury, serious chest and abdominal trauma. All dummies seated on the non-struck side of both vehicles exhibited kinematics that suggest a high risk of serious belt related injuries.

The outcome of this paired crash testing is comparable to other side impact crash tests that have been previously conducted with passenger vehicles. A known countermeasure to reduce the risk of head injury for struck side occupants is inflatable curtain technology. The

PAIRED CRASH TESTING of a 15 PASSENGER VAN & MFAB

countermeasures to limit occupant ejection from the seat belts and subsequent occupant to occupant contact in all types of passenger vehicles are still under development. Potential candidate measures include improved designs of restraints and seats and the introduction of in-board side airbags.

The testing conducted by Transport Canada represents very specific combinations of vehicle models, speed at time of impact, dummies used, seating configuration, etc. The results do not lend themselves to generalization on how the same vehicle models would behave under different testing conditions or how different vehicles (other models of 15 passenger vans, MFABs) would behave under the same (or different) testing conditions. Therefore, Transport Canada does not draw any general conclusions concerning the crashworthiness of 15 passenger vans nor the MFAB types of vehicles.

The results of the paired crash testing project do not support the need for further testing at even more severe conditions (eg. heavier bullet vehicle, higher speed of impact, both vehicles in motion, oblique angle of impact), where the casualties would be expected to be exacerbated. Hence, no additional crash testing will be conducted.

FUTURE WORK

As part of its regulatory program, Transport Canada will continue to assess the applicability of countermeasures for the protection of occupants of light-duty vehicles in general, during side impact collisions. This will be undertaken in the context of the Canada-U.S. Regulatory Cooperation Council and the activities thereunder.

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