Occupant Protection in Transit Buses: Do We Have the Correct Tools?

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Abstract Crash tests were conducted to compare the effect that stiffening of the front-end structure of a bus might have on the driver and the passengers. Five frontal offset transit bus crash tests were conducted with transit buses at 40 km/h and a 40 %, driver-side offset. The test parameters for the two pairs of crash tests were matched except for some structural strengthening that was added to the front end of one striking bus from each pair. Anthropometric Test Devices (ATDs) were installed in the driver seat and at various locations on-board the striking vehicle. ATD positions were matched for each pair of tests. The strengthening of the bus reduced the intrusion into the occupant space of the driver and resulted in negligible changes in peak acceleration (<2 g) of the passenger compartment of the bus. In all tests, the acceleration of the striking bus never exceeded 10 g. All ATDs placed in the passenger compartment of the striking bus (with the exception of a restrained ATD in a wheelchair) either impacted the seat in front with the head or were ejected from the seat. Research efforts should be directed towards improving energy absorption and the development of complementary tools to better assess injury mechanisms.

Keywords ATD, frontal, offset, structural reinforcement, transit bus.

I. INTRODUCTION

In pre-pandemic Canada, 12.4 % of commuters used public transit [1]. Ridership on transit buses had been increasing since the mid-1990s [2], increasing by an estimated 2.4 %, or approximately 50 million passengers between 2017 and 2018 [3]. The incidence of fatality or serious injury associated with transit bus crashes has been low; the United States National Highway Traffic Safety Administration (NHTSA) reported that in 2017, 0.4 % of vehicles involved in fatal crashes were buses [4].

In 2013, a double-decker bus collided with a passenger train in Ottawa, Canada. The collision was investigated by the Transportation Safety Board (TSB) [5]. The photo in Fig. 1 shows the extensive destruction to the front of the bus. According to the TSB analysis, the left front corner of the transit bus, travelling at 8 km/h collided with the front, left side of the locomotive as shown in the schematic. The train had reduced its speed to 69.2 km/h.

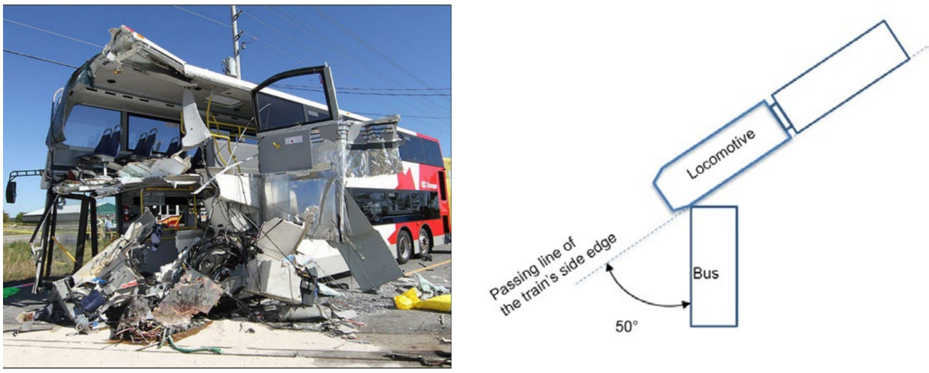

Fig. 1. (Left) Photo of damage to the bus and (right) schematic of the 2013 collision between a bus and a passenger train.

The collision resulted in five occupant ejections, six fatalities, and 34 injuries. As part of the report, the TSB suggested that "a more robust front structure and crash energy management design might have reduced the damage to the bus and prevented the loss of a protective shell for the occupants". In 2015, the TSB issued the

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recommendation that "the Department of Transport develop and implement crashworthiness standards for commercial passenger buses to reduce the risk of injury".

In response to the TSB recommendations, Transport Canada launched a multi-year research programme to investigate the crashworthiness of transit buses and to provide scientific evidence in support of possible future regulatory initiatives. Specifically, the research programme was designed to examine the effects of structural stiffness and energy management on the protection of transit bus drivers and passengers during frontal crashes.

The protection of passengers during a crash relies on striking a balance between the strength of the vehicle structure and the dissipation of the crash energy. A very stiff shell, for example, may remain intact and prevent ejections, but the energy that would have been dissipated during the crushing and destruction of that shell must somehow be directed away from the occupants. Energy management becomes all the more challenging for unrestrained passengers (without seat belts) who may be seated or standing.

An important and necessary part of the research programme involves the interpretation of Anthropometric Test Device (ATD) responses within the context of the transit bus occupant space. ATDs were designed for the monitoring of passenger car safety regulations. In these applications, the ATDs are placed in prescribed positions and their motions are constrained by seatbelts, airbags, and the occupant compartment. The effects of the non-humanlike, stiff, upright seated posture of the ATDs may be less significant in this environment. However, in a transit bus, where the ATD movements are not restrained, the stiffness of the ATDs can influence the ATD trajectory and the body region that may be impacted. Additional tools may be required to help describe potential injury mechanisms and improve the accuracy of injury risk prediction.

This paper presents the results of five full-scale transit bus crash tests. To our knowledge, Transport Canada is the only organisation to have conducted full scale transit bus-to-transit bus crash tests with ATDs placed in the driver seat and throughout the passenger compartment. The objective of this multi-year transit bus research programme is to investigate the crashworthiness of transit buses in order to support evidence-informed regulatory initiatives.

II. METHODS

For reasons of availability and cost, decommissioned single level buses were used instead of double decker buses. Since the objective of the study was to evaluate the effect of structural reinforcement on occupant response, a simplified configuration at a greatly reduced collision energy was selected. It was also important that the configuration be repeatable to allow for comparison between the baseline and reinforced test samples and that the full vertical profile of the driver side be in contact with the target vehicle.

A total of five transit bus crash tests were conducted. Test weights for all bullet and target buses are presented in TABLE A I. In each crash test, the driver side of a moving bus (Striking Vehicle) impacted the right rear corner of a stationary bus (Target Vehicle). The impact speed of the Striking Vehicle was 40 km/h and the overlap at impact was 40 %, as shown in Fig. 2.

Test 1 and Test 2 were conducted with two decommissioned New Flyer D40i buses purchased from the City of Ottawa; In Test 1, which served as the baseline or reference test, both buses were in their original condition upon delivery. In Test 2, the same vehicles were used, but the positions were reversed, i.e., the Target Vehicle in Test 1 became the new Striking Vehicle.

In Test 3 and Test 4, Test 3 served as the baseline, the Striking Vehicle in Test 4 was reinforced. Since Test 3 and Test 4 were conducted with four identical decommissioned New Flyer B40 LF buses, there was no need to re-use a bus as had been done previously.

Test 5 was a single test conducted with two identical Nova Bus LFS buses. Due to time limitations, its paired test could not be conducted. Results for Test 5 are nonetheless presented in this paper. These buses were built on a completely different platform. While all buses in the test sample shared the same exterior dimensions (40 feet long and 102 inches wide), the LFS model did not feature a second door in the middle of the bus and offered less seating space at the rear of the bus. The layout of the seats was different but most importantly the characteristics of the seats and the height of the seatbacks are different from the sample of New Flyer buses.

Fig. 2. Front and top view of vehicle alignment for Test 1 and Test 2

Structural Reinforcement of Striking Vehicle Test 2 and Test 4

Once Test 1 and Test 3 were completed, the front of the striking vehicle was inspected and the damage was measured and documented. Structural reinforcements were proposed for the damaged structures and shared with the bus manufacturer. Structural reinforcements, shown in Fig. 3, were added to the Striking Vehicle of Test 2 and Test 4. To the greatest extent possible, the reinforcements added in Tests 2 and 4 were comparable to each other. Materials used included square A500 steel Hollow Structural Section tubes (HSS) and flat steel plates of varying size and thickness. The three key elements of the reinforcements were located at:

1. The window frame: 2"x2" HSS tubes were installed around the window frame and diagonally across the window;
2. The service panel: 2"x2" HSS tubes were installed around the service panel;
3. The bumper: an 8' long 2"x10" HSS tube was installed behind the original bumper.

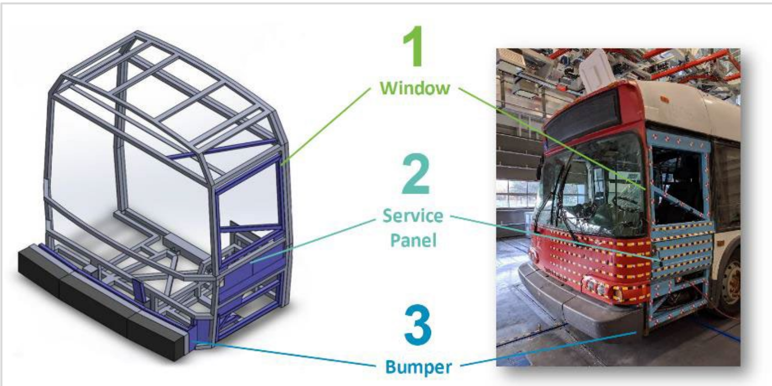

Fig. 3. CAD drawing (left panel) and photo (right panel) showing the key reinforcements added for Test 2. In both images, the reinforcements are shown in blue.

Bus Deformation Measurements & Instrumentation

To quantify the deformation of the bus, targets were placed across the front of the Striking Vehicle, and the pre- and post-test positions of each target were recorded to quantify their displacements in three dimensions (3D). The longitudinal components of the displacement measurements were used as indicators of intrusion.

The deceleration/acceleration responses of the striking and target buses were recorded using accelerometers at the approximate centres of gravity (CGs) of the vehicles. On the striking bus, accelerometers were also placed on the floor under each seat occupied by an ATD.

ATD Placement

The intent of the ATD selection and placement was to measure responses in as many seating locations as possible and for both child and adult transit bus occupants. A total of 11 ATDs were installed at various locations on-board the Striking Vehicle in Test 1, Test 2, Test 3 and Test 4; and 18 ATDs were on board in Test 5. The layouts for ATD placement are shown in Fig. A1 where the upper schematic is for Test 1 and Test 2, the bottom is for Test 3 and Test 4. ATD positions were matched for each pair of tests, this included ATD serial number and placement of arm, leg and feet positions. The placement of ATDs in Test 5, which was not part of a paired comparison, is shown in Fig. A2. The ATDs placed in the driver locations were restrained with a lap belt. With the exception of the ATD in the wheelchair (Test 5), all ATDs were unrestrained.

The ATDs were representative in size of an average size man (Hybrid III and WorldSID 50th percentile), a small woman or teenager (Hybrid III or THOR 5th percentile), a 10-year-old child (Hybrid III or Q10), and a six-year-old child (Hybrid III and/or Q6). Each ATD was instrumented to record head, chest and pelvic accelerations, and neck forces. Some ATDs also had instrumentation in the upper and lower legs to measure the forces caused by contact with the seat in front of the ATD.

III. Results

Post crash photos of the front left corner of the bus for the two pairs of comparative tests are presented in Fig. 4 (Test 1 and Test 2) Fig. 5 (Test 3 and Test 4), and observations are summarised in TABLE A II. The A-pillar was disrupted at the base and sheared at mid-height in Test 1. In Test 3 the A-pillar sheared at the base. On the driver side, the bumper was folded back and into the space previously occupied by the base of the A-pillar. Little to no deformation was found on the underbody structure of Test 1, 2 and 3. The photos in the right panels of Fig. 4 and Fig. 5, suggest that the reinforcements of the Striking Vehicle for Test 2 and Test 4 have limited deformation at the front of the bus and the driver occupant space.

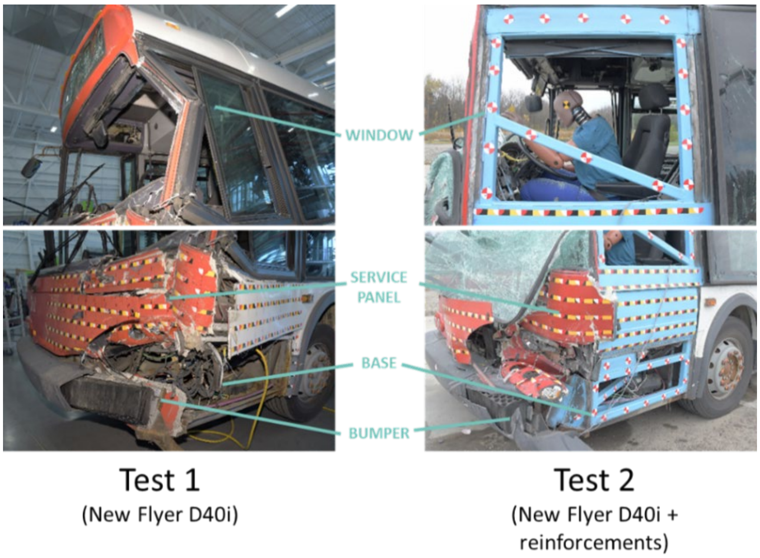

Fig. 4. Post-test photos of the Striking Vehicle in Test 1 and Test 2 (pair of New Flyer D40i buses with and without reinforcements).

Test 3
(New Flyer B40 LF)

Test 4
(New Flyer B40 LF + reinforcements)

Fig. 5. Post-test photos of the Striking Vehicle in Test 3 and Test 4 (pair of New Flyer B40 LF buses with and without reinforcements.

A post-test photo of the bus in Test 5 is shown in Fig. A3. The A-pillar/windshield frame of the striking bus was displaced rearward into the occupant compartment. The front body panel of the bus was also displaced rearward, along with the bumper. The bumper was deformed primarily where it met with the right edge of the target bus. No major rearward displacement was visually observed along the side of the bus or front undercarriage. The frame surrounding the driver's sliding window does not appear to be displaced.

The maximum longitudinal displacement on the lower half of the bus was 366 mm in Test 1 compared to 260 mm in Test 2. At the A-pillar near the window frame, the displacement was reduced from 261 mm in Test 1 to 22 mm in Test 2.

The maximum longitudinal displacement (with the exception of the A-pillar) of the bus in Test 3 was 457 mm compared to 207 mm in Test 4. At the A-pillar near the window frame, the displacement was reduced from 273 mm in Test 3 to 80 mm in Test 4. The topmost point of the A-pillar (Test 4) was displaced 28 mm rearward of the pre-test location while the base of the A-pillar was displaced back 166 mm and down 78 mm.

In Test 5, the longitudinal displacements at the A-pillar near the window frame measured 290 mm and 226 mm at the base of the A-Pillar. The greatest longitudinal displacement along the front of the bus was 313 mm, located 400 mm to the left of centre and just below the windshield. Displacement of the underbody of the bus in Test 5 appeared to be negligible. On the struck side, deformation of the lateral beam supporting the bumper and the longitudinal beam measured 65 mm vertically and 50 mm longitudinally.

Accelerations Responses of the Bus

Fore-aft acceleration responses were significantly lower than the values typically observed in light duty vehicles tested in comparable crash test configurations. As shown in Fig. A4 Appendix A, all peak fore-aft acceleration responses of the Striking Vehicle were slightly greater in Test 2 than in Test 1. The greatest peak acceleration recorded in Test 1 was 7.0 g compared to 9.7 g in Test 2. There was no obvious relationship between the individual accelerometer locations and the region of impact.

Placement of the accelerometers on the two striking buses for Test 3 and Test 4 were also matched. As shown in Fig. A4, all peak fore-aft acceleration responses of the Striking Vehicle were slightly reduced from 9.0 g in Test 3.0 compared to 7.8 g in Test 3. The accelerations at the driver locations could not be included in the analysis due to excessive noise.

The peak acceleration at the CG of the striking bus in Test 5 was 8.5 g. The accelerations at each place in the striking bus (Fig. A4) ranged from 8.0 to 16.9 g, tending higher at the front of the bus.

ATD Responses

Responses for all ATDs are presented in TABLE A III for Test 1 and Test 2, in TABLE A IV for Test 3 and Test 4, and in TABLE A V for Test 5. Head and femur responses of the ATD in the driver location were lower in Test 2 than in Test 1. In Test 4, the chest and the femur responses of the driver were lower than in Test 3. Video views indicate that the ATD head contacted the rear leading edge of the target bus in Test 1 resulting in a head acceleration of

166 g but in Test 2, the head contacted the shattering glass and recorded a head acceleration of 54 g (Fig. 6). No head strikes were observed in either Test 3 or Test 4 (Fig. 7).

In Test 1, the steering wheel became wedged into the space between the rib cage and the ATD abdomen (below the sternum) while in Test 2, no penetration of the steering wheel into the ATD abdomen was observed. In Test 3, the lower rim of the steering wheel loaded the ATD at the sternum resulting in a peak chest deflection of 46 mm while in Test 4, the steering wheel was displaced downward below the sternum resulting in only 6 mm of deflection.

Left and right femur loads were each approximately 4 kN in Test 1 but were reduced by 76 % and 64 % to 1 kN and 1.5 kN, respectively, in Test 2. The left and right femurs recorded peak forces of 3.7 kN and 6.8 kN in Test 3. These loads were reduced to 3.0 kN and 3.7 kN, respectively, in Test 4.

In Test 5 the ATD in the driver position translated forward in an upright posture until the lower rim of the steering wheel impacted the chest below the sternum. The head and torso then continued to rotate about the steering wheel until the head impacted the upper rim, this resulted in a peak head acceleration of 105 g and a neck shear of 0.67 kN. The left and right femur loads were 4.3 kN and 2.7 kN, respectively.

Passenger responses in the paired tests were mixed. Seven of the 10 ATD responses were higher in Test 2 than in Test 1, while only two of the ten ATD responses were higher in Test 4 than in Test 3. For example, in Test 2, the Hybrid III 6-year-old ATDs seated in position C (row 1) recorded a pelvis acceleration of 172 g compared to 135 g in Test 1; the Hybrid III 6-year-old in position G (row 3) recorded a pelvis acceleration of 95 g in Test 2 compared to 60 g in Test 1; and neck shear was greater for the ATDs placed in positions F, G, and H in Test 2 compared to Test 1. The Hybrid III 5th percentile seated in position I (upper level) recorded a left femur load of 4 kN in Test 2 compared to 2 kN in Test 1. Differences between the ATD responses in Test 3 and Test 4 were less notable. Exceptions included the WorldSID seated on the side-facing seat behind the driver which recorded a greater lateral neck shear (2.6 kN) in Test 3 compared to Test 4 (0.4 kN). The arm of the Hybrid III 10-year-old seated in position C of row 1 became entangled with the armrest of the side-facing seat located in front of the ATD in Test 3 whereas in Test 4 the ATD catapulted over the armrest. Pelvis accelerations were 87 g and 35 g, respectively for this ATD.

Fig. 8 compares the frequency of head impacts and ejections (partial or complete) for the five tests. The numbers represent the peak resultant head accelerations [g]. Seat locations where the ATD head was observed to contact a barrier, handlebar or the seat back located in front of the ATD are identified in red. ATDs placed in locations identified in yellow were either completely or partially ejected from the seat. Location D in Test 5 represents the Hybrid III 50th secured in a forward-facing wheelchair. This was the only restrained passenger and as indicated by the green colour code, the only ATD not to have had a head impact or been ejected in Test 5. Fig. 9 illustrates examples of head strikes that were observed while Fig. 10 shows post-test photo of the Hybrid III 10-year-old entangled with the armrest, and freeze frame images of the Hybrid III 5th crashing through the barrier and a Q6 being launched over a barrier.

ATDs that were ejected, either completely or partially from the seat, were found suspended from adjacent structures, seated upright or lying on their sides. Examples of the less than humanlike final resting positions are shown in Fig. 11 and Fig. 12.

Fig. 6. Freeze frames of the driver ATD at peak head excursion in Test 1 and Test 2 (pair of New Flyer D40i buses with and without reinforcement).

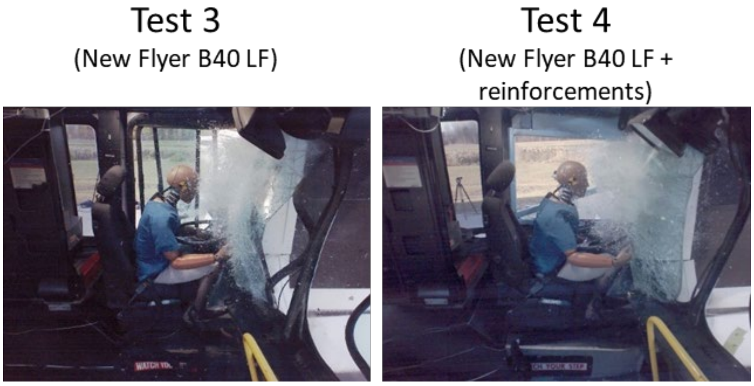

Fig. 7. Freeze frames of the driver ATD at peak head excurison in Test 3 and Test 4 (pair of New Flyer B40 LF buses with and without reinforcement).

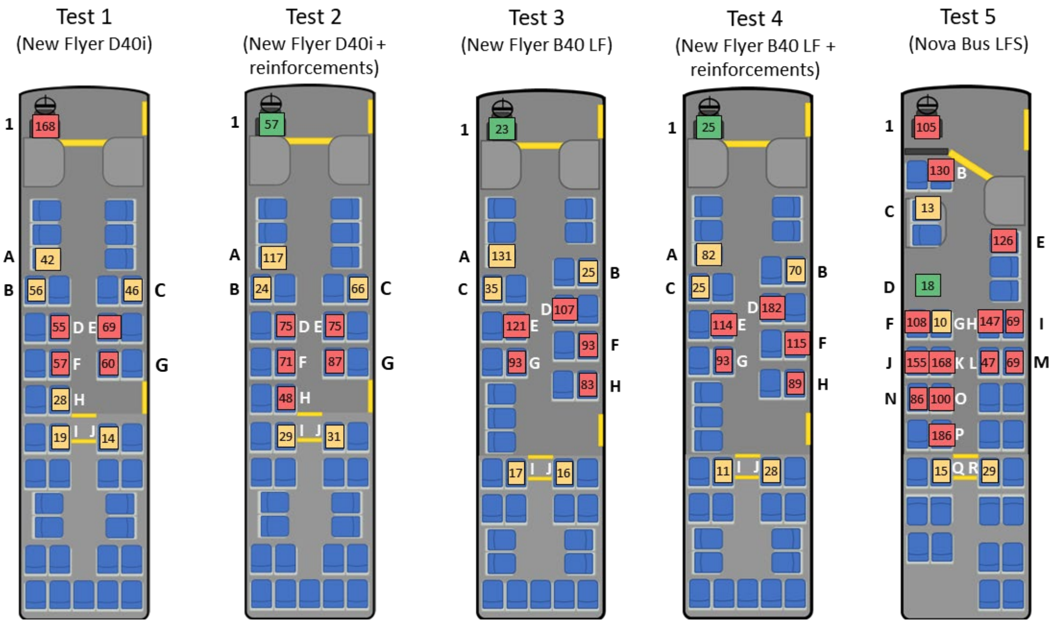

Fig. 8. Peak resultant head acceleration of each ATD on-board the Striking Vehicles, colour coded to indicate whether no head contact was observed (green), the head impacted the seat or barrier in front (red), or ejection from the seat was observed (yellow).

Fig. 9. Freeze frame images showing examples of head contact with seatbacks and hold bars.

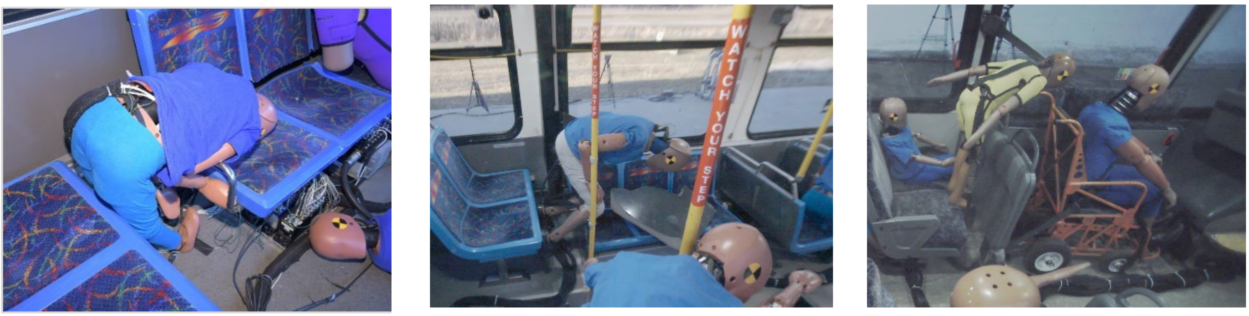

Fig. 10. Freeze frame images and photos of ejected passengers.


Fig. 11. Post-test photos of final positions of the Hybrid III 6-yr-old, 5th percentile and 10-yr-old.

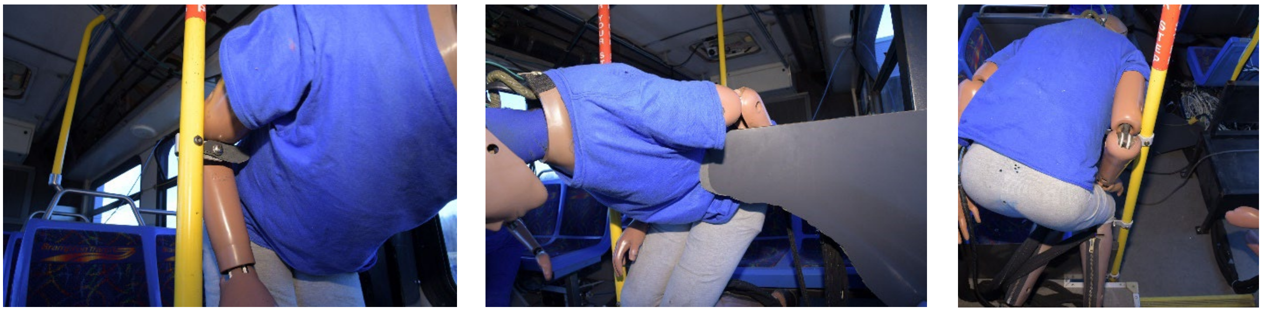
Fig. 12. Post-test photos of final positions of the Hybrid III 5th percentile interaction with barrier hardware.

IV. Discussion

This research programme was designed to examine the effects of structural stiffness and energy management on the protection of transit bus drivers and passengers during frontal crashes. Five tests in total were conducted. Of these, two pairs were configured to provide a direct comparison of a bus that had not been modified to one that had had the front left corner or driver side of the bus strengthened. The strengthening, while not representative of a practicable or indeed achievable countermeasure, was intended to add structural resistance in the crash zone.

Two different bus models were used for each matched pair. In the first pair of tests, the acceleration recorded in Test 2 at the CG of the Striking Vehicle (strengthened) and at each occupied seating location increased by approximately 2 g while in Test 4 the accelerations of the Striking Vehicle dropped by approximately 1 g. The visual observations of deformation, 3D point streams, and accelerometer data, suggest that the energy of the impact was absorbed in large part through the structures surrounding the front left wheel. It would appear that in the model of bus used in Test 3 and Test 4, less energy from the collision was transferred to the passenger compartment. Designs of this this type that allow the driver compartment to be strengthened to limit intrusion without transferring the collision energy to the passenger compartment could be beneficial to the driver and the passengers.

In all five tests, peak accelerations at the CG and on the floor beneath occupied seats were below 10 g. The only exception was in Test 5 where accelerometers installed at the driver location and on the floor at location B, behind the driver, recorded peak accelerations that ranged from 12 to 17 g. The accelerometers in the driver compartment were disrupted by the deforming structures in the paired tests so the data could not be analysed.

In both pairs of tests, the strengthening reduced intrusion into the driver occupant space. As a result, the loads to the ATD were either reduced or redirected. The redirection of forces may be an effective countermeasure to protect the driver but the Hybrid III 50th together with its limited instrumentation is not suitable to evaluate such countermeasures. A case in point is the interaction between the steering wheel and the ATD that was observed in the two paired tests. In Test 1 the rim of the steering wheel penetrated the space below the sternum whereas in Test 2 the rim contacted but did not appear to penetrate. Visually, the penetration observed in Test 1 appeared more injurious but since the interactions occurred below the potentiometer neither outcome could be quantified. In Test 3, the rim of the steering wheel impacted the sternum. The risk of injury was identified by an elevated chest deflection (46 mm) and not the chest acceleration (17 g). While the results that were observed in Test 3 would be expected to cause serious if not life-threatening thoracic injury, improvements or the exacerbation thereof, resulting from the redirection of loads that were observed in Test 4, could not be quantified.

In a series of sled tests [6], the possibility of head injuries due to passenger-to-passenger contact was noted. The authors also identified the head, neck, and femur as the primary injury regions. In another study [7], it was observed in sled tests that adult ATDs contacted the seatback in front with their knees and struck the seat in front with the head. These findings appear to be consistent with accident analyses [8], where it was noted that injured seated passengers were most likely to have contacted vertical and horizontal handrails. According to traffic studies [6][8], over half of bus occupant fatalities between 1999 and 2003 were attributed to non-ejected fatal impacts (53.8 %), almost double the fraction of fatalities attributed to ejection (28.2 %).

Head strikes were observed for all ATDs placed on the lower level that had a seat back or a full barrier in front (as in location B in Test 5). The orientation of the head, the point of contact on the head and the trajectory of the ATD all appear to have influenced the magnitude of the head acceleration. For example, the 50th percentile ATD placed in the fourth row (Location H) in Test 1 and Test 2 contacted the seat in front with the knees and the upper body flexed forward. In Test 1, the ATD neck contacted the handrail whereas in Test 2, the chin contacted the handrail. Minor differences in the initial pre-test positions between the two tests were identified and likely contributed to the observed differences in motion. In both instances head resultant accelerations were below 50 g but the peak neck shear was recorded at -829 N at 181 ms for the direct neck contact in Test 1, compared to 2,768 N at 150 ms for the chin contact in Test 2. The neck is instrumented with force transducers at the top and base of the neck but there is no instrumentation that is currently available to allow for the measurement of contact loads to the neck. The risk of direct impact to the neck, which could result in serious injury for a human passenger, cannot be quantified with current tools. Use of any injury metric, in isolation of video analysis could lead to an inaccurate characterisation of injury risk.

ATDs that were placed in the elevated seats in the rear portion of the bus tore the barrier and/or were thrown over the barrier or the seat back in front (Test 5). This suggests that in certain frontal crashes, the barrier, as tested, may not be sufficient to prevent occupant displacement into the forward space and subsequent occupant-to-occupant interaction. Furthermore, the exposed hardware used to secure the barrier in place that is shown in Fig. 12, could expose a human passenger to a risk of soft tissue injury, i.e., laceration, that cannot be detected by the ATD.

All ATDs that did not have a seatback in front were either partially ejected, or fully ejected and landed on the floor. The recorded responses tended to be lower than the responses of ATDs that remained in their seats. This is likely due to the orientation of the instrumentation and the absence of human like articulation of the ATD. In the Hybrid III, THOR and Q series the instrumentation is oriented to measure in the fore-aft direction. If an ATD is launched out of the seat and thrown to the floor the instrumentation may not be adequate to record the true response. Another consideration is that none of the Hybrid III, THOR or WorldSID ATDs can assume any position other than an upright seated position.

Currently, there are no specific requirements designed to manage injury risk in transit buses. By comparison, in passenger vehicles, several regulations and technologies exist to reduce the force of contact with hard interior surfaces of the vehicle. C/FMVSS 201 *Occupant protection in interior impact*, for example, prescribes a test protocol and defines injury criteria for head impacts with instrument panels, and requires the use of energy-absorbing materials for sun visors and armrests. In contrast to the well-established methods for the evaluation of occupant protection in passenger cars, improvements to the current instruments are needed if effective regulatory requirements are to be developed.

Limitations

Only three different transit bus models were included in the study. Given the limitations of the ATDs it was not possible to investigate the injury mechanisms for passengers who may be standing or leaning forward, for example. Similarly, due to the rigid upper legs, which acted as blockers between the ATD and the seat in front, the interaction of the lower leg with the front seat structure could not be evaluated in this study.

V. CONCLUSIONS

The addition of structural reinforcement to the front of the bus was found to mitigate certain injuries for the driver in two different transit bus models. The added structural reinforcement increased the acceleration response in the passenger compartment of one bus model but not the other. ATD responses for all five tests conducted suggest that several interior structures such as grab handles and seatbacks could be a source of injury, even in a low to moderate collision. The current fleet of ATDs is not sufficient for the evaluation of injury mechanisms and potential countermeasures in transit buses. Further research should explore the development of complementary tools to help counter ATD limitations and improve countermeasures.

VI. ACKNOWLEDGEMENTS

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VII. DISCLAIMER

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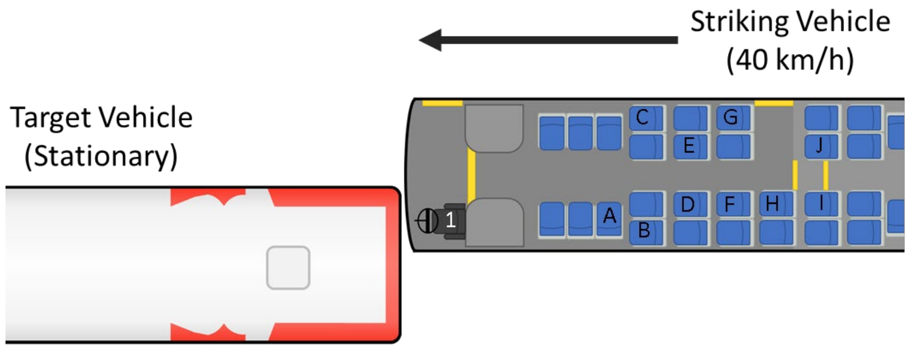
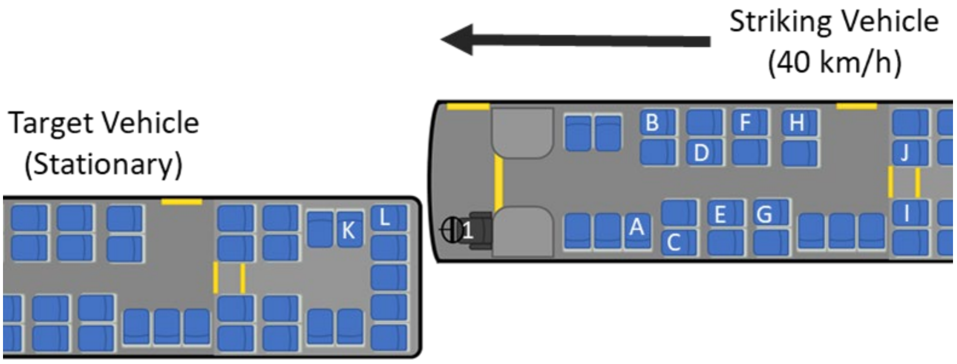
IX. APPENDIX A

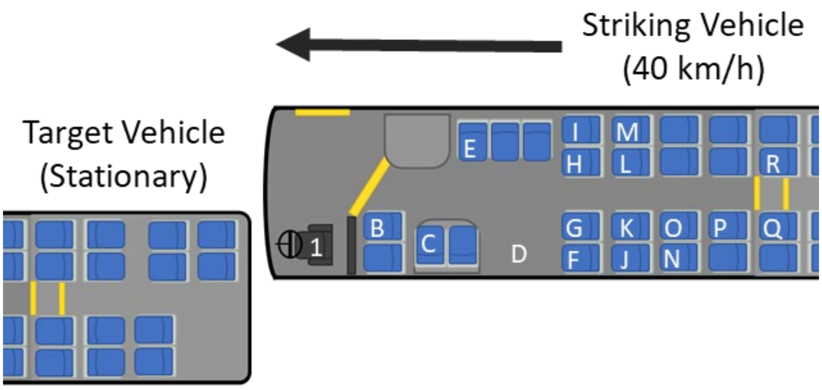


Legend Test 1 and Test 2	
1	Hybrid III 50th %
A	WorldSID 50th
B, J	Hybrid III 10-yr-old
C, G	Hybrid III 6-yr-old
D, E, F, I	Hybrid III 5th %
H	Hybrid III 50th %



Legend Test 3 and Test 4	
1	Hybrid III 50th %
A	WorldSID 50th %
C, J	Hybrid III 10-yr-old
B, F, H	Hybrid III 6-yr-old
D, E, G, I	Hybrid III 5th %
K	WorldSID 5th %
L	Hybrid III 50th %

Fig. A1. Schematic of the crash test ATD placement in Tests 1&2 (above) and Tests 3&4 (below).



Legend Test 5	
1, Q	Hybrid III 50th %
D	Hybrid III 50th % in a wheelchair facing forward
J, K, P, R	Hybrid III 5th %
O	THOR 5th %
C, E	WorldSID 5th %
B, I	Hybrid III 10-yr-old
H	Q-Series 10-yr-old
F, M, N	Hybrid III 6-yr-old
G, L	Q-Series 6-yr-old

Fig. A2. Schematic of the crash test ATD placement in Test 5.

TABLE A I

TEST WEIGHTS [KG]

		BULLET	TARGET	MODEL
Comparison pair #1	Test 1	14320	13375	New Flyer D40i
	Test 2	13870	13200	New Flyer D40i
Comparison pair #2	Test 3	13035	12850	New Flyer B40LF
	Test 4	12600	12450	New Flyer B40LF
	Test 5	12860	12295	NOVA Bus LFS

TABLE A II

SUMMARY OF DAMAGE OBSERVED IN TEST 1, TEST 2, TEST 3 AND TEST 4.

Bus Location	Test 1 Observation (New Flyer D40i)	Test 2 Observation (New Flyer D40i + reinforcements)	Test 3 Observation (New Flyer B40 LF)	Test 4 Observation (New Flyer B40 LF + reinforcements)
Bumper support beam	Visibly bent	Deformation not visually obvious	Visibly bent	Deformation not visually obvious
Base	A-pillar disruption	No apparent A-pillar disruption	A-pillar disruption	No apparent A-pillar disruption
Window	A-pillar bent	A-pillar not visibly bent	A-pillar bent	A-pillar not visibly bent
Service Panel	Deformation	Slight deformation	Deformation	Slight deformation
Underbody	No apparent deformation observed			Significant skew

Fig. A3. Pre- and post test photos of Striking Vehicle in Test 5.

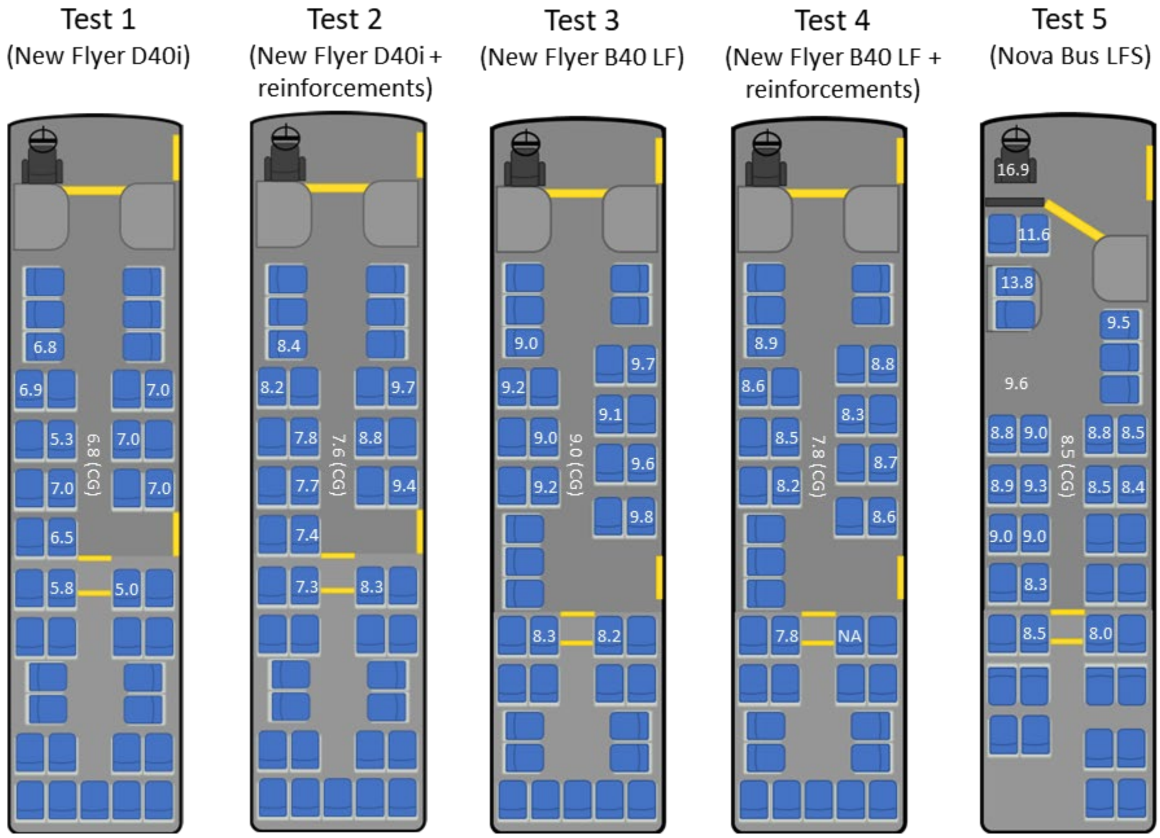


Fig. A4. Peak fore-aft acceleration responses of the bus as a function of occupied seat location.

TABLE A III
TEST 1 AND TEST 2.

ATD	Test No.	Head [g]	Neck shear [N]	Chest [g]	Pelvis [g]	Left Femur [N]	Right Femur [N]
Driver (50th percentile)	1	168	-404	17	31	4138	4199
	2	57	-510	14	24	966	1472
Side-facing ATD (50th percentile)	1	42	403	40*	26	–	–
	2	117	-2159	51*	35	–	–
Position B (10-year-old)	1	56	651	25	106	–	–
	2	24	432	26	141	–	–
Position C (6-year-old)	1	46	–	17	135	–	–
	2	66	492	18	172	–	–
Position D (5th percentile)	1	55	1952	17	23	2026	2552
	2	75	2135	20	28	2586	2457
Position E (5th percentile)	1	69	1524	16	19	1656	2194
	2	75	1589	20	21	1965	2390
Position F (5th percentile)	1	57	2102	18	28	2458	1746
	2	71	2937	21	36	2065	2761
Position G (6-year-old)	1	60	997	21	60	–	–
	2	87	1381	25	95	–	–
Position H (50th percentile)	1	28	-829	15	15	2363	2574
	2	48	2768	24	15	2687	2743
Position I (5th percentile)	1	19	-185	16	21**	2117	1798
	2	29	-227	10	22**	4006	2355
Position J (10-year-old)	1	14	-128	8	22	1062	1495
	2	31	-279	22	17	1235	1079

*Peak resultant acceleration at T4
**Peak fore-aft acceleration

TABLE A IV
TEST 3 AND TEST 4.

ATD	Test No.	Head [g]	Neck shear [N]	Chest [g]	Pelvis [g]	Left Femur [N]	Right Femur [N]
Position 1	3	23	-516	24	44	3673	6784
(50th percentile)	4	25	-331	18	59	2956	3337
Position A	3	131	-2588	55**	19	-	-
*(WS 50th percentile)**	4	82	413	34**	15	-	-
Position B	3	25	-142	18	55	2054	2117
(6-year-old)	4	70	713	32	52	1578	1216
Position C	3	35	269	27	87	-	-
(10-year-old)	4	25	243	10	35	-	-
Position D	3	107	1714	22	43	-	-
(5th percentile)	4	182	2224	23	45	-	-
Position E	3	121	2560	24	52	2905	2664
(5th percentile)	4	114	2317	24	32	2471	3270
Position F	3	93	1109	32	56	-	-
(6-year-old)	4	115	1000	27	62	-	-
Position G	3	93	2335	26	27	2036	2061
(5th percentile)	4	93	2286	24	31	2621	2665
Position H	3	83	1155	25	58	-	-
(6-year-old)	4	89	1637	51	53	-	-
Position I	3	17	293	13	16	1761	1667
(5th percentile)	4	11	-122	6	23	2373	1546
Position J	3	16	-190	11	19	1298	951
(10-year-old)	4	28	-534	24	23	1449	1259

*WS: WorldSID side impact ATD
**Peak resultant acceleration at T4

TABLE A V
TEST 5

ATD	Test No.	Head (g)	Neck Shear (N)	Chest (g)	Pelvis (g)	Left Femur (N)	Right Femur (N)
Position 1 (HIII 50th)	5	105	-668	23	38	4304	2695
Position B (HIII 10-year-old)	5	130	1463	17	48	-	-
Position C (WS 5th)	5	13	261	15*	33	-	-
Position D (HIII 50th percentile)	5	18	-690	19	-	-	-
Position E (WS 5th percentile)	5	126	-413	-	37	-	-
Position F (HIII 6-year-old)	5	108	1428	35	30	-	-
Position G (Q6)	5	10	-242	10	14	-	-
Position H (Q10)	5	147	254	19	22	-	-
Position I (HIII 10-year-old)	5	69	1448	20	46	2730	2385
Position J (HIII 5th percentile)	5	155	1405	16	24	2729	1654
Position K (HIII 5th percentile)	5	168	1697	14	15	1690	1551
Position L (Q6)	5	48	702	34	18	-	-
Position M (HIII 6-year-old)	5	69	713	13	13	320	375
Position N (HIII 6-year-old)	5	86	917	20	19	-	-
Position O (THOR 5th)	5	100	1418	34**	18	-	-
Position P (HIII 5th percentile)	5	186	2426	21	21	1952	1903
Position Q (HIII 50th percentile)	5	16	-303	9	9	1343	1905
Position R (HIII 5th percentile)	5	29	-327	7	52	1970	3401

*T4 resultant acceleration
**T6 resultant acceleration