



Memorandum

U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**

Subject: Motorcoach Safety Research

Date: **APR 24 2009**

From: Stephen R. Kratzke
Associate Administrator
Rulemaking

Reply to
Attn of:

To: Docket No. NHTSA-2007-28793

Thru: *for* Steve Wood
Acting Chief Counsel

Attached is the Agency's analysis of the motorcoach roof crush and rollover testing that was performed on two different 40 foot motorcoaches.

Please submit it to the docket NHTSA-2007-28793.

Attachment:

Motorcoach Roof Crush/Rollover Testing Discussion Paper, March 2009

Motorcoach Roof Crush/Rollover Testing

Discussion Paper

March 2009

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Executive Summary

This paper discusses the results of the roof crush/rollover testing that was performed on two different motorcoach models as part of the August 2007 comprehensive safety plan on motorcoach safety. The testing was done to evaluate two existing roof crush/rollover test procedures on two older motorcoaches: Federal Motor Vehicle Safety Standard (FMVSS) No. 220 and Economic Commission for Europe (ECE) r.66 complete vehicle test. The objective of this testing was to determine the feasibility of establishing a roof crush performance requirement for motorcoaches sold in the United States (U.S.)

The agency purchased two 12,200 mm (40 feet) 1992 Motor Coach Industries (MCI) model MC-12, and two 12,200 mm (40 feet) 1991 Prevost model LeMirage motorcoaches for the testing. MCI and Prevost vehicles were selected for roof strength and occupant survivable space research assessment because they were similar in size, and exhibited visible differences in construction. The most discernable difference between these two models was that the Prevost LeMirage had smaller side windows and more roof support pillars than the MCI MC-12.

The FMVSS No. 220 test applies a uniformly distributed compressive load (equivalent to 1.5 times the unloaded vehicle weight of the bus), on the roof of the bus along its longitudinal centerline using a 915 mm (3 feet) wide platen that is 305 mm (1 foot) shorter than the bus length. The requirements are that the bus roof does not compress more than 130 mm (5.118 inches) and the emergency exits remain operable. It was determined that the test protocol could be adapted to test motorcoaches with only minor changes to the test device. However, neither the MCI nor the Prevost bus was able to meet the 1.5 times the unloaded vehicle weight (UVW) required for school buses. The MCI bus was able to achieve 0.91 x UVW prior to the front of the bus collapsing and hydraulic test device running out of stroke. The Prevost bus was able to achieve 1.17 x UVW prior to the front of the bus collapsing and hydraulic test device running out of stroke. It should be noted that neither of these buses were required or designed to meet the FMVSS No. 220 requirements.

The ECE r.66 test tips the bus sideways off an 800 mm (31.5 inches) step onto a hard surface. The bus typically strikes the hard surface near the intersection between the sidewall and the roof. The regulation specifies that there can be no encroachment upon the survivable space as determined by templates that are 1,250 mm (50.2 inches) tall and are tapered from the sidewall a distance of 150 mm (5.9 inches) at the bottom and 400 mm (15.8 inches) at the top. The testing determined that this protocol could be adapted to motorcoaches built for the U.S. market. However, again as in the FMVSS No. 220 test, neither of the two buses was able to meet the test requirements. Each bus encroached upon the survivable space template located at the front of the bus.

While not required by the ECE r.66 tests, accelerometers were placed along the top section of the bus to measure the accelerations when the bus struck the ground. In addition, two instrumented 50th percentile male test dummies, one restrained with a lap/shoulder belt and the other unrestrained, were also included in each bus. The testing determined that the average acceleration near the top of the bus was 7.59 g's for the MCI bus and 8.20 g's for the Prevost bus. This testing also determined that unrestrained passengers could receive high head and neck injury values

depending on how the passenger falls while the bus is rolling over. One of the unrestrained dummies received a head injury criterion (HIC_{15}) of 4,132 and a neck injury value for axial compressive force of -17,732 N, far exceeding the thresholds of 700 for the head and -4,000 N for the neck.

The testing determined that either of these test protocols could be adapted for motorcoaches sold in the United States (U.S.). Since both the buses tested did not comply with the FMVSS No. 220 or the ECE r.66 requirements, it was not possible to objectively assess the relative stringency of the two test protocols on a quantitative analysis. However, based on a qualitative assessment it appears that the FMVSS No. 220 test protocol may be more stringent because both buses failed to support its own unloaded vehicle weight and reached the maximum displacement allowed for school buses at 70 and 100 percent of the unloaded vehicle weight. But the ECE r.66 test is more representative of a motorcoach rollover event and is better for assessing if emergency exits come unlatched during rollovers which may help prevent some of the ejection fatalities that are the principal safety concern with motorcoach transportation.

1.0 Introduction

In August 2007, the agency published “NHTSA’s Approach to Motorcoach Safety.” The goal of the comprehensive safety plan included a review of motorcoach safety issues and the course of action NHTSA will pursue to address them. The August 2007 document identified four approaches that would most effectively and expeditiously realize improvement in motorcoach safety:

- Seat Belts on motorcoaches
- Fire Safety of motorcoaches
- Upgrade emergency evacuation
- Improved roof crush/rollover protection

A summary of NHTSA’s activities in these four motorcoach safety priority areas along with research results obtained thus far is discussed in the 2009 ESV paper by Prasad et al¹. The focus of this paper is to present and discuss the results of the roof crush/rollover testing that was performed on two different motorcoach models. The testing was done to evaluate the relative stringency and practicality of two existing roof crush test procedures: Federal Motor Vehicle Safety Standard (FMVSS) No. 220² and Economic Commission for Europe (ECE) r.66³. The objective of this testing was to determine the feasibility of adapting existing roof crush rollover performance standards to motorcoaches sold in the United States (U.S.).

¹ Prasad, A., Sutula, D., Saul, R., Hinch, J., Hott, C., Valvo, L., Beretzky, S., “Status of NHTSA’s Motorcoach Safety Plan,” Paper No. 09-0448, 21st International Technical Conference on the Enhanced Safety of Vehicles Conference (ESV), June, 2009.

² 49 CFR 571.220 School bus rollover protection

³ Uniform Technical Prescriptions Concerning The Approval Of Large Passenger Vehicles With Regard To The Strength Of Their Superstructure

2.0 National Transportation Safety Board (NTSB) Recommendations

In November 1999, NTSB issued two safety recommendations to the agency regarding roof crush resistance of motorcoaches. This was part of the six safety recommendations that were issued in conjunction with the 1999 NTSB Highway Special Investigation Report, *Bus Crashworthiness Issues*⁴. NTSB initiated this special investigation to determine whether additional measures should be taken to better protect bus occupants. Below are the safety recommendations regarding motorcoach roof strength:

“H-99-50 (MW): In 2 years, issue performance standards for motorcoach roof strength that provide maximum survival space for all seating positions and that take into account current typical motorcoach window dimensions.”

“H-99-51: Once performance standards have been developed for motorcoach roof strength, require newly manufactured motorcoaches to meet those standards.”

In the 1999 report, NTSB cited an October 1971 rollover of a 1970 Motor Coach Industries (MCI) motorcoach to justify a roof crush safety recommendation. However, recent events involving motorcoaches also indicate that roof strength may continue to be an area which could provide improved occupant protection. In January 2008, there was a rollover incident involving a 2007 MCI motorcoach near Mexican Hat, Utah that, according to newspaper and media reports, rolled down (one complete 360 degree roll) a 12.2 meters (40 feet) embankment. As a result, the entire roof of the motorcoach sheared off and 50 of the 52 occupants were ejected. There were nine fatalities and a number of occupants sustained serious injuries. NTSB is currently investigating the incident. Below are pictures of the bus:

⁴ National Transportation Safety Board. 1999, *Bus Crashworthiness Issues*. Highway Special Investigation Report NTSB/SIR-99/04. Washington, DC.



Figure 1: Mexican Hat Bus Rollover, Front View



Figure 2: Mexican Hat Bus Rollover, Oblique Left Side



Figure 3: Mexican Hat Bus Rollover, Side View Looking Down Embankment

3.0 Previous Related Motorcoach Safety Research

From 2003 to 2006, NHTSA and Transport Canada had a joint program that focused on improving glazing and structural integrity of motorcoaches to prevent ejections, using standard coach windows and different variations of glazing and bonding techniques⁵. The research focused on finite element modeling of a Prevost model XLII, 13,420 mm (44 feet) in length with an unloaded weight of 15,490 kg (34,150 lbs) during a rollover. Simulations were conducted to determine the force applied to the roof during the ECE r.66 rollover test, and during other scenarios such as sliding into fixed objects. The key findings of the research with respect to force on the roof indicated that a force of 1,149,529 N (258,424 lbs) (approximately 7.6 g's average acceleration) with an applied vector angle of 29 degrees relative to the bus longitudinal-transverse plane was achieved during the rollover. It was determined that the average force distribution

⁵ Motor Coach Glazing Retention Test Development for Occupant Impact During a Rollover, August 2006, Docket No. NHTSA-2002-11876-15.

along the top corner of the bus was approximately 86 N/mm (490 lbs/in) along the length of the bus. However, no test procedure was established under this research program.

In the document “NHTSA’s Approach to Motorcoach Safety” NHTSA identified improving the roof strength of motorcoaches as one of the four approaches that would most effectively and expeditiously realize improvement in motorcoach occupant protection. Therefore, NHTSA initiated a research program to evaluate existing test protocols and performance requirements presented in Section 4.

4.0 Existing Test Protocols Examined

In accordance with the approach to address roof crush/rollover protection in motorcoaches, two existing roof crush test procedures and their associated performance requirements for buses were examined to determine the feasibility of their application to motorcoaches sold in the United States. One procedure is that specified in FMVSS No. 220 – School Bus Rollover Protection and the other is that specified in ECE r.66 for large passenger vehicles with regard to the strength of their superstructure. The following sections provide a description of the two test procedures and their associated performance requirements.

4.1 FMVSS No. 220

FMVSS No. 220, which specifies performance requirements for school bus rollover protection, became effective on April 1, 1977 and has not substantially changed since its inception. The standard applies to all school buses, and as indicated in the notice of proposed rulemaking⁶, the regulation was adopted from an existing industry standard of the School Bus Manufacturers Association. The standard specifies that when a uniformly distributed load equal to 1.5 times the unloaded vehicle weight is applied to the roof of the vehicle’s body structure through a force

⁶ 40 FR 8570 February 1975

application plate, the downward vertical movement at any point on the application plate shall not exceed 130 mm and the emergency exits must be operable during and after the test. The load is applied using a platen positioned along the longitudinal centerline of the school bus that is 914 mm (36 inches) wide and 305 mm (12 inches) shorter in length than the vehicle roof.

4.2 ECE r.66 Uniform Technical Prescriptions Concerning The Approval Of Large Passenger Vehicles With Regard To The Strength Of Their Superstructure

ECE r66 applies to single-deck, rigid or articulated vehicles, designed and constructed for the carriage of more than 22 passengers in addition to the driver and crew. It requires a complete vehicle test but allows other options (discussed later). The other options are all based on the complete vehicle test described in section 4.2.1.

4.2.1 Complete Vehicle Test

In the complete vehicle test, the vehicle with suspension blocked is placed on a tilting platform and is slowly raised to its unstable equilibrium position (Figure 4). The vehicle is tipped over from a raised platform with a nominal depth of 800 mm (31.50 in) into a ditch, having a horizontal, dry and smooth concrete ground surface. If the bus is not fitted with occupant restraints it will be tested at unloaded vehicle weight. If the bus is fitted with occupant restraints it will be tested at total effective vehicle mass which includes half the total weight of the occupants.

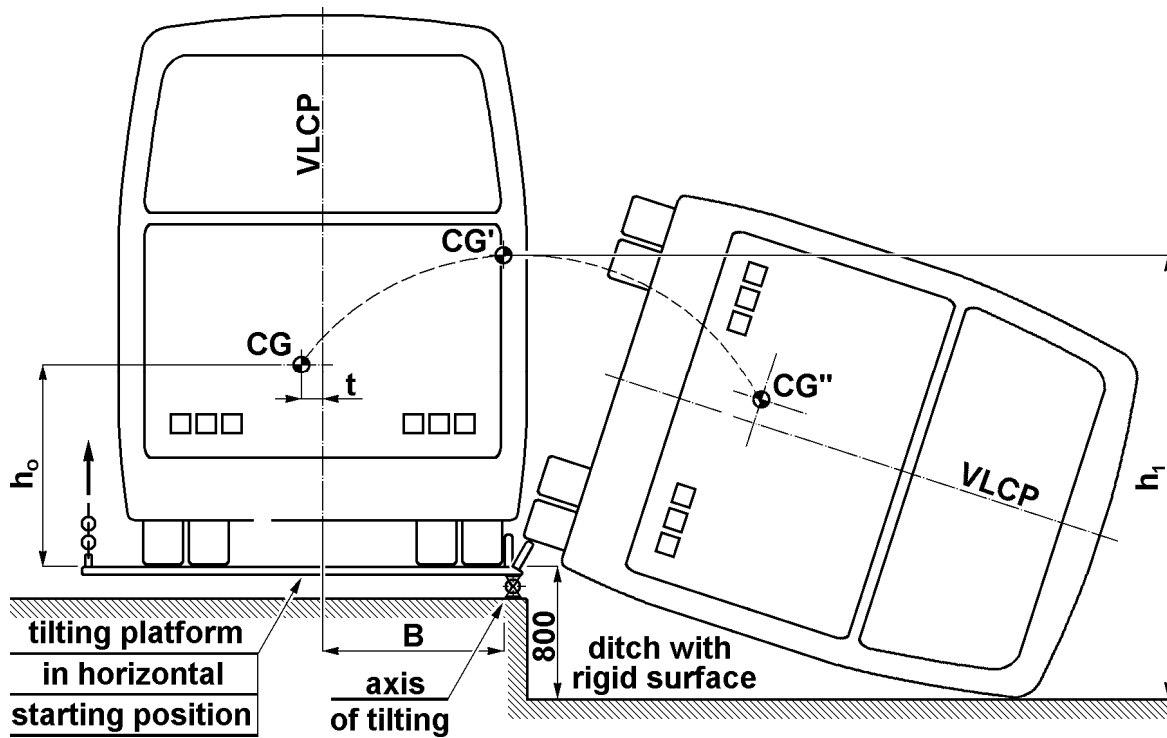


Figure 4: ECE r.66 Rollover Test

The performance specifications of ECE R.66 requires that the superstructure of the vehicle has sufficient strength to ensure that the residual space during and after the rollover test on the complete vehicle is unharmed. Templates for residual space are placed inside the vehicle at a minimum in the front and rear of the bus. No part of the vehicle which is outside the residual space at the start of the test (e.g. pillars, safety rings, luggage racks) shall intrude into the residual space during the test. The envelope of the vehicle's residual space is defined by creating a vertical transverse plane within the vehicle which has the periphery described in Figures 5 and 6.

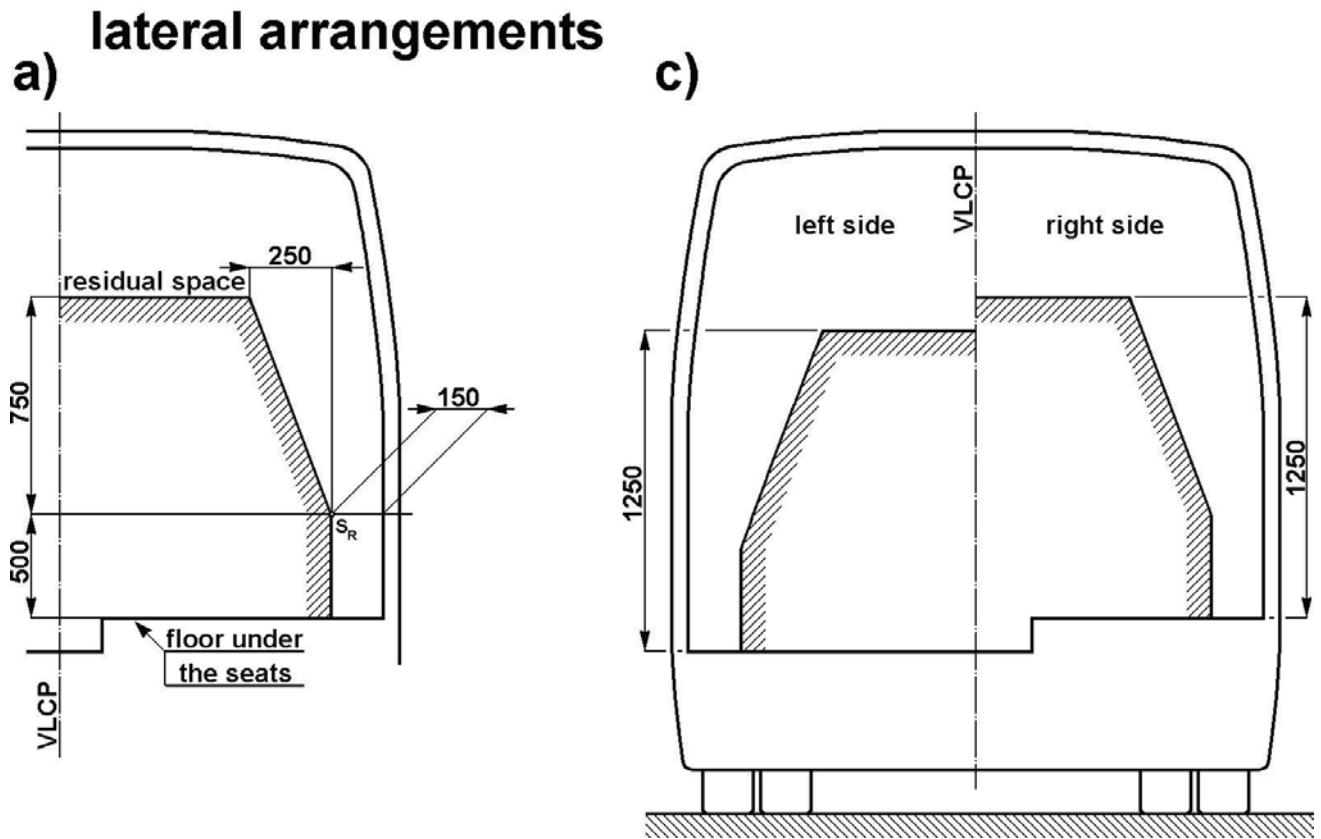


Figure 5: Residual Space Template End View

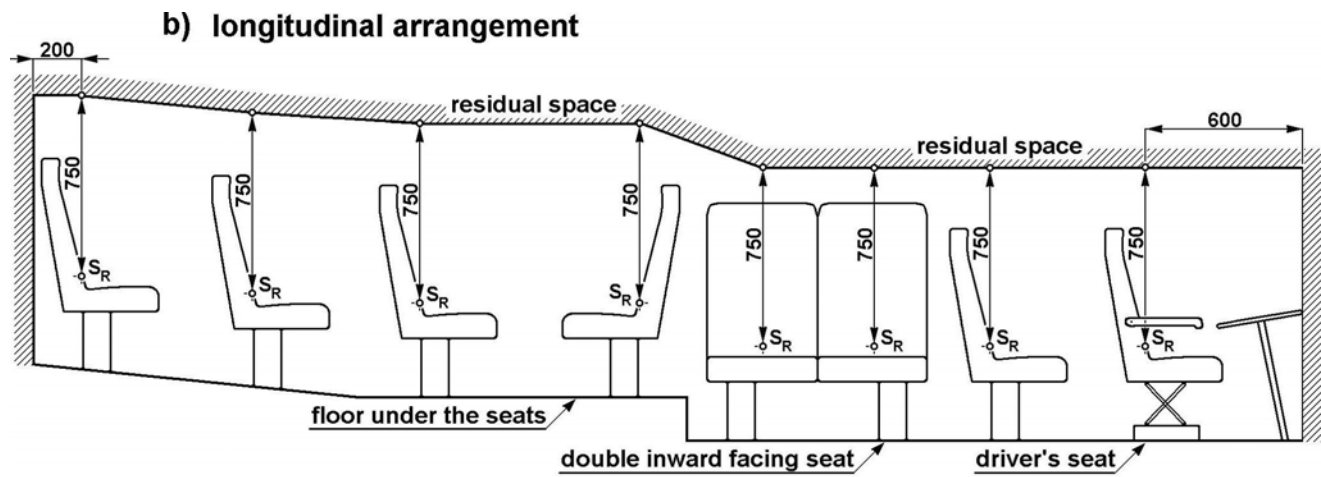


Figure 6: Residual Space Template Side View

In addition to the complete vehicle test, manufacturers have the following options for complying with the ECE r.66 requirements:

1. Rollover test of body sections representative of the vehicle
2. Quasi-static loading tests of body sections
3. Quasi-static calculations based on testing of components
4. Computer simulation (finite element analysis) of complete vehicle

These options are intended to be equivalent representation of the complete vehicle rollover test.

4.2.2 Rollover Test Of Body Sections Representative of The Vehicle

Under this option a body section of the bus is tested which includes at least two windows or a window and a door. Mass and bracing are added so that it provides the same center of gravity and rigidity as the complete vehicle. The body section is tipped over from the same 800 mm high tilting platform as that used in the complete vehicle test.

4.2.3 Quasi-Static Loading Tests of Body Sections

Under this option a quasi-static loading test is conducted on a body section of the bus. The body section includes at least two windows or doors. The body section is securely attached to the test bench through a rigid under frame. A uniformly distributed load is then applied to the body section with a rigid beam which is longer than the body section to simulate striking the ground in a rollover test as shown in figure 7.

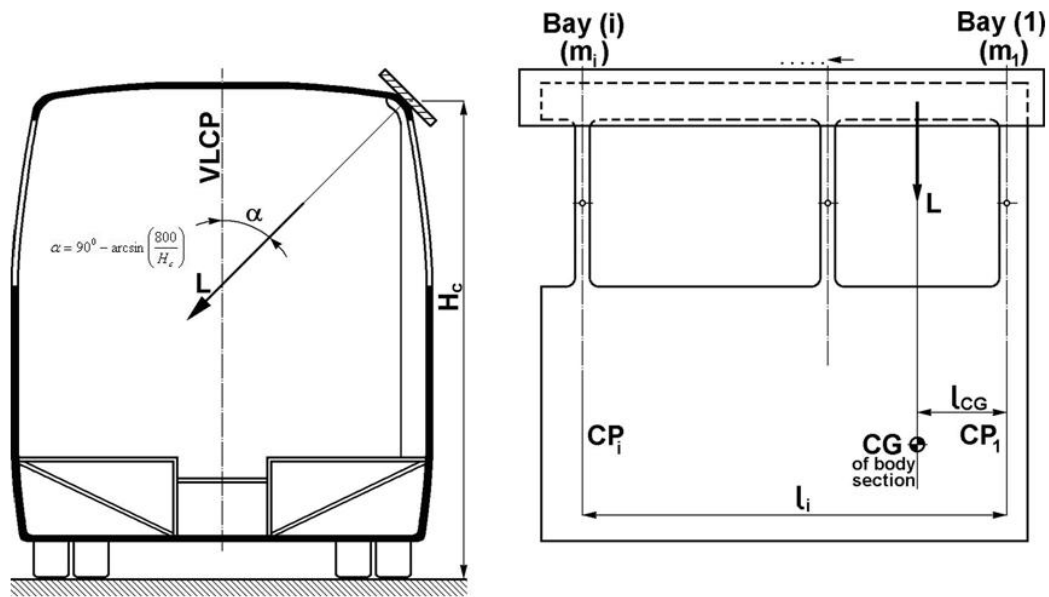


Figure 7: Application of load to body section

The load is increased gradually, taking measurements of the associated deformation until the residual space is invaded by one of the elements of the body section. This option specifies that the energy absorbed by the body section is at least 75 percent of the estimated energy absorbed by the body section in the complete vehicle rollover test.

4.2.4 Quasi-Static Calculations Based On Testing of Components

Under this option, the manufacturer calculates the deformation with a computer algorithm to determine the amount of energy absorbed in the quasi-static test. The manufacturer must determine the plastic hinges (PH) and/or the plastic zones (PZ) of the bus structure and shown in figure 8. The algorithm must contain at least 100 incremental “quasi-equal” steps when making the calculation. The load application is applied as shown in figure 9. As in the quasi-static test,

the absorbed energy of the body section must be at least 75 percent of the amount of energy it would have received in the complete vehicle rollover test.

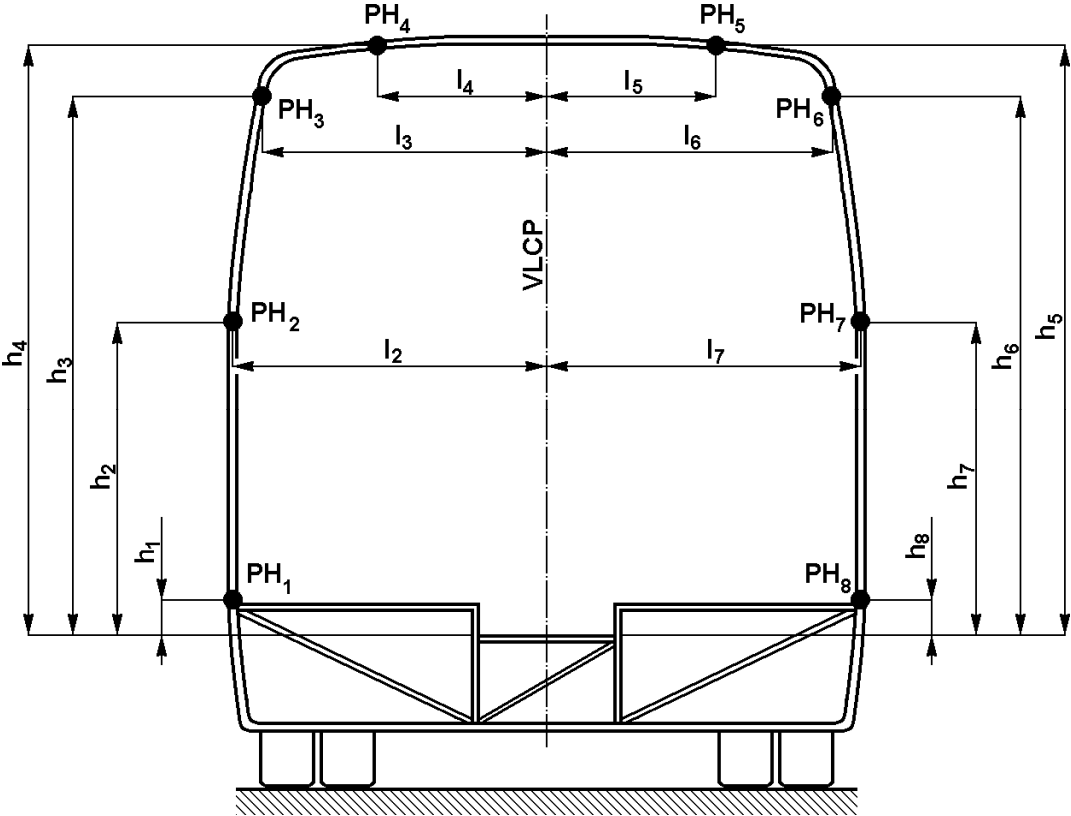


Figure 8: Geometrical parameters of plastic hinges on a bay

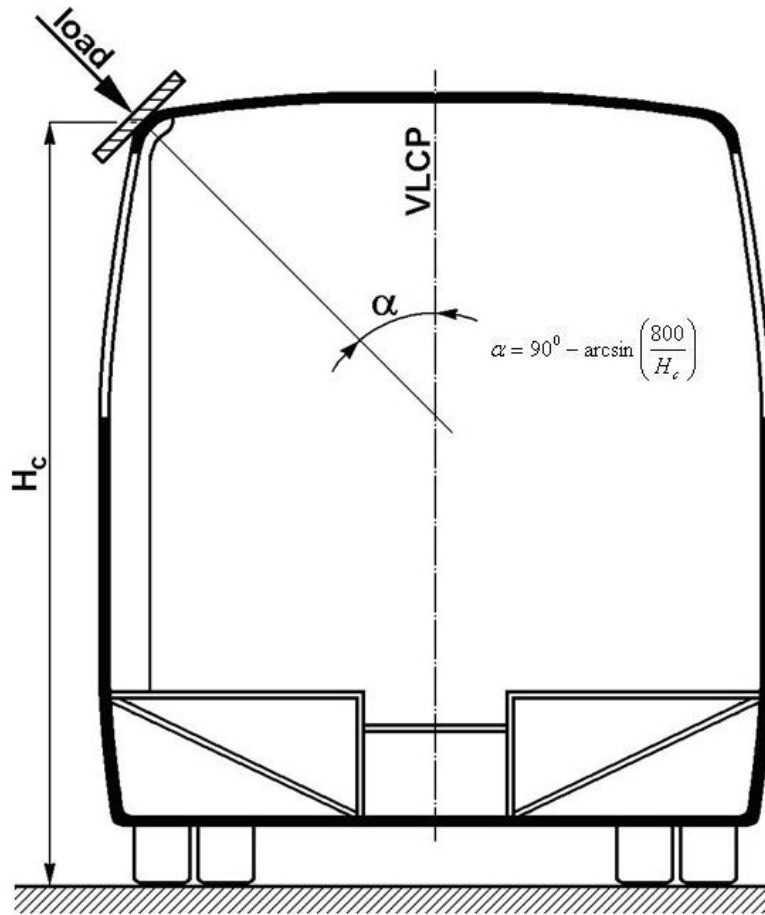


Figure 9: Load application to the superstructure

4.2.5 Computer Simulation Of Rollover Test On Complete Vehicle

Under this option, the manufacturer uses a computer program that is capable of simulating the physical behavior of a complete vehicle test described in section 3.2.

5.0 Test Vehicles Selected

The agency purchased two 12,200 mm (40 feet) 1992 Motor Coach Industries (MCI) model MC-12, and two 12,200 mm (40 feet) 1991 Prevost model LeMirage motorcoaches. The vehicles were selected for this research program such that they would represent the range of roof characteristics (such as design, material, pillars, shape, etc.) of motorcoach roofs in the U.S. fleet.

MCI and Prevost vehicles were selected for roof strength and occupant survivable space research assessment using the FMVSS No 220 and ECE r.66 test protocols because they were similar in size and weight but exhibited visible differences in construction. The most discernable difference between these two models was that the Prevost LeMirage had smaller side windows and more roof support pillars. Table 1 presents selected information about each of the buses. Figures 10 and 11 are photographs of the test buses.

Table 1: Manufacturer’s bus specifications

| Make | Model | Model Year | Unloaded Vehicle Weight | GVWR | Window Length (mm) | Window Height (mm) |
|---------|----------|------------|---------------------------|---------------------------|--------------------|--------------------|
| MCI | MC-12 | 1992 | 12,474 kg (27,500 lbs) | 17,146 kg (37,800 lbs) | 1310 | 685 |
| Prevost | LeMirage | 1991 | 12,426 kg (27,395 lbs) | 18,145 kg (40,000 lbs) | 815 | 1040 |



Figure 10: 1992 MCI, MC-12



Figure 11: 1991 Prevest, LeMirage

Each of the buses was outfitted with residual space templates as specified in ECE r.66 as shown in Figure 12. The location of the residual space templates is presented in Table 2.

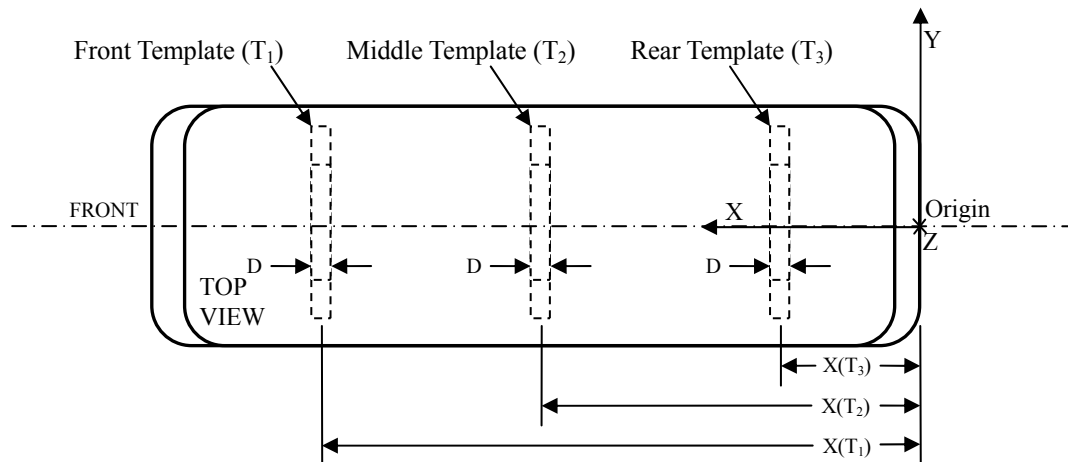
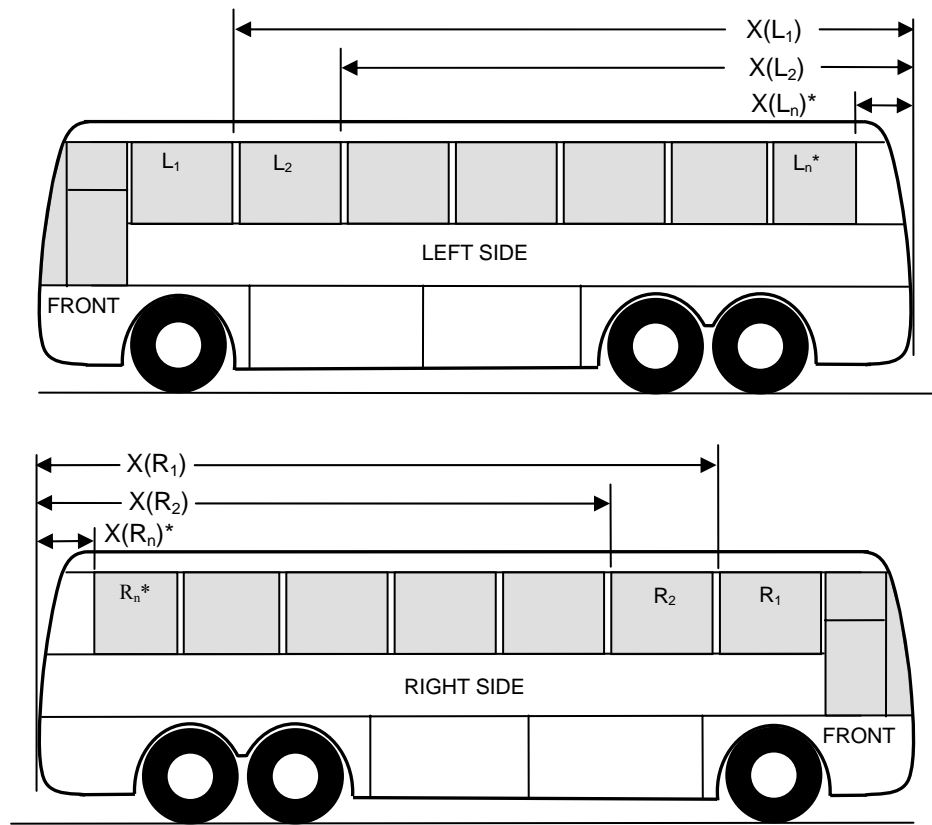


Figure 12: Residual Space Template Locations

Table 2: Residual Space Template Locations

| Bus | Bus Rearmost Surface to Center of Front Template (X(T ₁)) | Bus Rearmost Surface to Center of Middle Template (X(T ₂)) | Bus Rearmost Surface to Center of Rear Template (X(T ₃)) |
|------------------|---|--|--|
| MCI MC-12 | 9,796 mm (386 in) | 6,316 mm (245 in) | 2,244 mm (88 in) |
| Prevost LeMirage | 10,481 mm (570 in) | 6,689 mm (263 in) | 2,379 mm (94 in) |

The location, size and type of side windows were measured as shown in Figure 13 and are presented for each bus in Tables 3 and 4.



* n = Side window number

Figure 13: Bus side window locations

Table 3: MCI Window Size, Location, and Type

| Window Location | Window Max. Length (mm) | Window Max. Height (mm) | Bus Rearmost Surface to Window Trailing Edge $X(L_n)^*$, $X(R_n)^*$ (mm) | Window Trailing Edge Pillar Width (mm) | Window Type | Emergency Exit Hinge and Latch Location | |
|-----------------|-------------------------|-------------------------|---|--|----------------|---|--------|
| | | | | | | Hinge | Latch |
| L ₁ | 1310 | 685 | 9486 | 57 | Emergency Exit | Top | Bottom |
| L ₂ | 1310 | 685 | 8015 | 57 | Emergency Exit | Top | Bottom |
| L ₃ | 1310 | 685 | 6545 | 57 | Emergency Exit | Top | Bottom |
| L ₄ | 1310 | 685 | 5064 | 57 | Emergency Exit | Top | Bottom |
| L ₅ | 1310 | 685 | 3600 | 57 | Emergency Exit | Top | Bottom |
| L ₆ | 1310 | 685 | 2114 | 57 | Emergency Exit | Top | Bottom |
| L ₇ | 1310 | 685 | 634 | 57 | Emergency Exit | Top | Bottom |
| R ₁ | 1310 | 685 | 9486 | 57 | Emergency Exit | Top | Bottom |
| R ₂ | 1310 | 685 | 8015 | 57 | Emergency Exit | Top | Bottom |
| R ₃ | 1310 | 685 | 6545 | 57 | Emergency Exit | Top | Bottom |
| R ₄ | 1310 | 685 | 5064 | 57 | Emergency Exit | Top | Bottom |
| R ₅ | 1310 | 685 | 3600 | 57 | Emergency Exit | Top | Bottom |
| R ₆ | 1310 | 685 | 2114 | 57 | Emergency Exit | Top | Bottom |
| R ₇ | 1310 | 685 | 634 | 57 | Fixed | -- | -- |

Table 4: Prevost Window Size, Location, and Type

| Window Location | Window Max. Length (mm) | Window Max. Height (mm) | Bus Rearmost Surface to Window Trailing Edge $X(L_n)^*$, $X(R_n)^*$ (mm) | Window Trailing Edge Pillar Width (mm) | Window Type | Emergency Exit Hinge and Latch Location | |
|-----------------|-------------------------|-------------------------|---|--|----------------|---|--------|
| | | | | | | Hinge | Latch |
| L ₁ | 815 | 1040 | 10,750 | 205 | Fixed | -- | -- |
| L ₂ | 815 | 1040 | 9350 | 205 | Fixed | -- | -- |
| L ₃ | 815 | 1040 | 8350 | 205 | Emergency Exit | Top | Bottom |
| L ₄ | 815 | 1040 | 7000 | 205 | Fixed | -- | -- |
| L ₅ | 815 | 1040 | 5775 | 205 | Emergency Exit | Top | Bottom |
| L ₆ | 815 | 1040 | 4955 | 205 | Fixed | -- | -- |
| L ₇ | 815 | 1040 | 3940 | 205 | Fixed | -- | -- |
| L ₈ | 815 | 1040 | 2920 | 205 | Emergency Exit | Top | Bottom |
| L ₉ | 815 | 1040 | 1880 | 205 | Fixed | -- | -- |
| L ₁₀ | 815 | 1040 | 860 | 205 | Emergency Exit | Top | Bottom |
| R ₁ | 815 | 1040 | 10,750 | 205 | Fixed | -- | -- |
| R ₂ | 815 | 1040 | 9350 | 205 | Fixed | -- | -- |
| R ₃ | 815 | 1040 | 8350 | 205 | Emergency Exit | Top | Bottom |
| R ₄ | 815 | 1040 | 7000 | 205 | Fixed | -- | -- |
| R ₅ | 815 | 1040 | 5775 | 205 | Emergency Exit | Top | Bottom |
| R ₆ | 815 | 1040 | 4955 | 205 | Fixed | -- | -- |
| R ₇ | 815 | 1040 | 3940 | 205 | Fixed | -- | -- |
| R ₈ | 815 | 1040 | 2920 | 205 | Emergency Exit | Top | Bottom |
| R ₉ | 815 | 1040 | 1880 | 205 | Fixed | -- | -- |
| R ₁₀ | 815 | 1040 | 860 | 205 | Fixed | -- | -- |

6.0 Test Results

The buses were tested to requirements in FMVSS No. 220 and ECE r.66 regulations neither of which are currently applicable to motorcoach buses manufactured for the United States.

6.1 FMVSS No. 220

The agency planned to test each motorcoach model to determine if they could meet the requirements in FMVSS No. 220⁷. The test plan used a modified FMVSS No. 220 protocol which included the following:

- Loading of the vehicle's roof to 1.5 times its unloaded vehicle weight⁸ (UVW) with appropriate platen.
- Assessment of emergency exit operation (FMVSS No. 217) before loading and at the intervals of ½, 1 and 1 ½ UVW loading (if safe to do so).
- Continued platen travel until a load of 1.5 x UVW is reached or until the maximum allowable displacement of 130 mm by the load application plate is reached, whichever comes first.
- Installation of residual space templates per ECE-r.66, Section 5.3 for comparison of the test results to the ECE-r.66 test protocol.

A computer controlled force application device designed and built by MGA Research Corporation was used for the test. The length of the force application plate was adjusted to approximately 305 mm (12 inches) less than the length of the vehicle roof in accordance with FMVSS No. 220. Two load beams were located underneath the vehicle at locations where significant frame structure was accessible. Four hydraulic actuators were attached to the load beams to lift the vehicle to the force application plate and apply the test load. The target maximum roof load was determined according to FMVSS No. 220 by multiplying the approximate UVW by 1.5. The UVW was obtained from two sources: the bus specification sheets and the load cell reading of the force application device. Video and transfer media were used to determine if any contact occurred between the vehicle interior and the residual space templates (shown in Figure 5 above) during the test.

⁷ Tested and documented as required in TP-220-02

⁸ The weight of the vehicle with maximum capacity of all fluids necessary for the operation of vehicle, but without cargo, occupants, or accessories that are ordinarily removed from the vehicle when not in use.

6.1.1 MCI

A 2224 N (500 lbs) pre-load was applied uniformly across the vehicle roof prior to the force application. The vertical movement of the force application plate relative to the load beams was measured from this initial, pre-loaded condition. The roof loading was paused momentarily at a force of 0.5 x UVW in order to measure the forces required to operate the emergency exits. The side emergency exits windows were operable after application of the 0.5 x UVW load was achieved. The loading was continued and the force application device reached its maximum displacement range before a load of 1.0 x UVW could be met. A peak load of 0.91 x UVW was achieved during the test. Approximately 13 seconds after the peak force was recorded, contact was made between the front residual space template and the left and right luggage racks. The test results are summarized in Table 5.

Table 5: MCI FMVSS No. 220 Test Results

| | |
|---|---|
| Test UVW(1) | 12,700 kg (28,000 lb) |
| Calculated Target Maximum Roof Load = 1.5 × UVW(1): | 19,050 kg (42,000 lb) |
| Maximum Roof Load Achieved During the Test: | 11,714 kg (25,825 lb) |
| Maximum Roof Deflection (measured at any single one of the four cylinders): | 654 mm (25.75 in) |
| Residual Template Contact: | YES(2) |
| Emergency Exit Operation | The emergency exit windows were operable after the 0.5 UVW and after the test. |
| Additional Test Observations: | The right front windshield fully lost retention and the left front windshield partially lost retention during the test. Windshield retention was lost just prior to reaching the maximum achieved load. |

NOTES:

- (1) This value was used for the maximum roof load calculation and is based on the UVW determined from the force application device, rounded up to 12,700 kg (28,000 lb).
- (2) The left and right luggage racks contacted the foremost residual space template (T1) prior to reaching the calculated maximum roof load.

Figures 14 and 15 present the force and displacements of each of the four hydraulic actuators versus time. Note that the force applied by the four actuators is equal during the test by design to provide uniform loading on the roof. However, the displacement at the front of the bus is significantly greater than that at the rear of the bus. The total force applied is the sum of the forces from each actuator and the maximum displacement is that measured at the front of the bus. Figure 16 is a plot of the total applied force (presented as a percentage of the unloaded vehicle weight) versus the maximum actuator displacement.

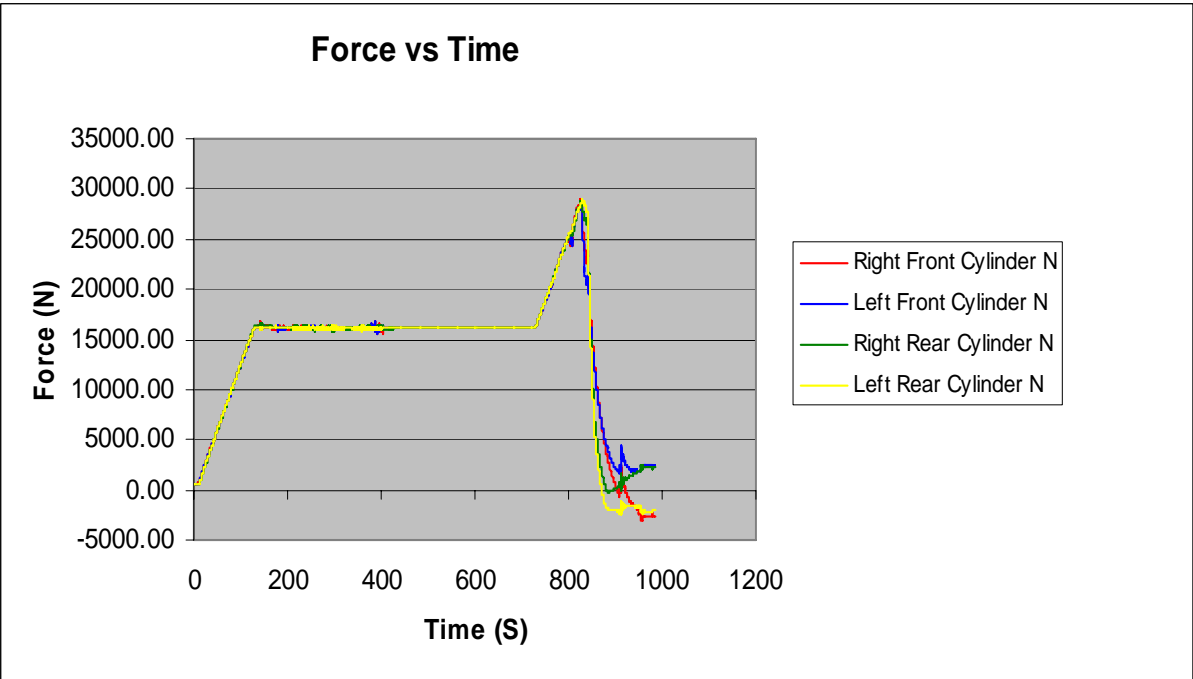


Figure 14: Actuator Force vs Time

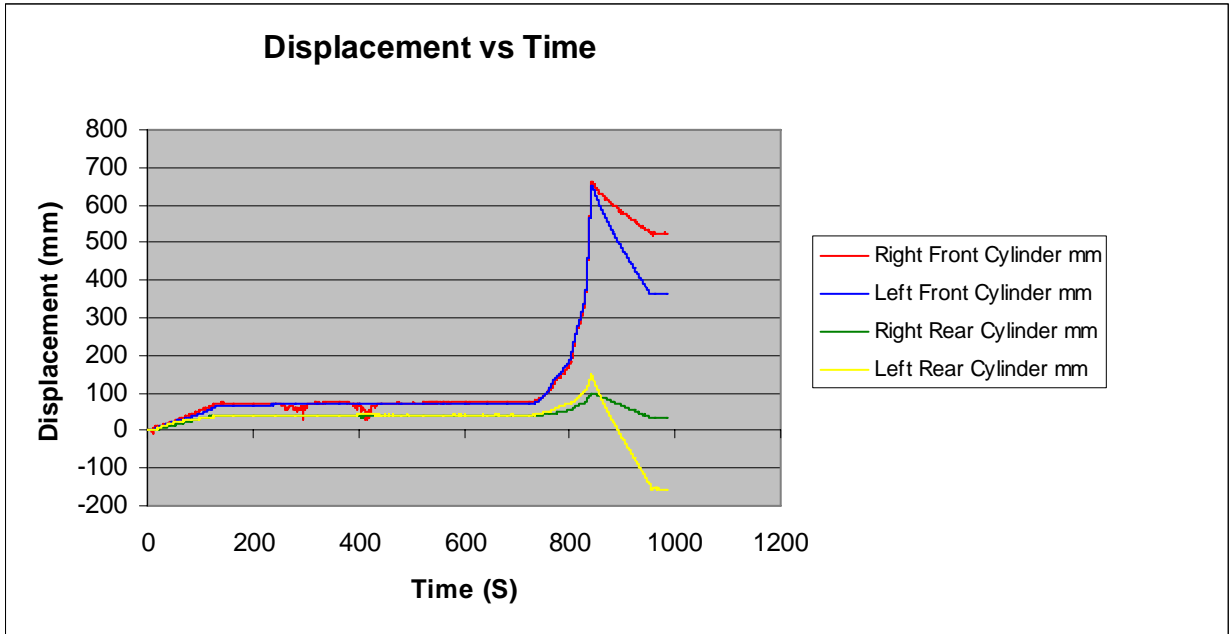


Figure 15: Actuator Displacement vs Time

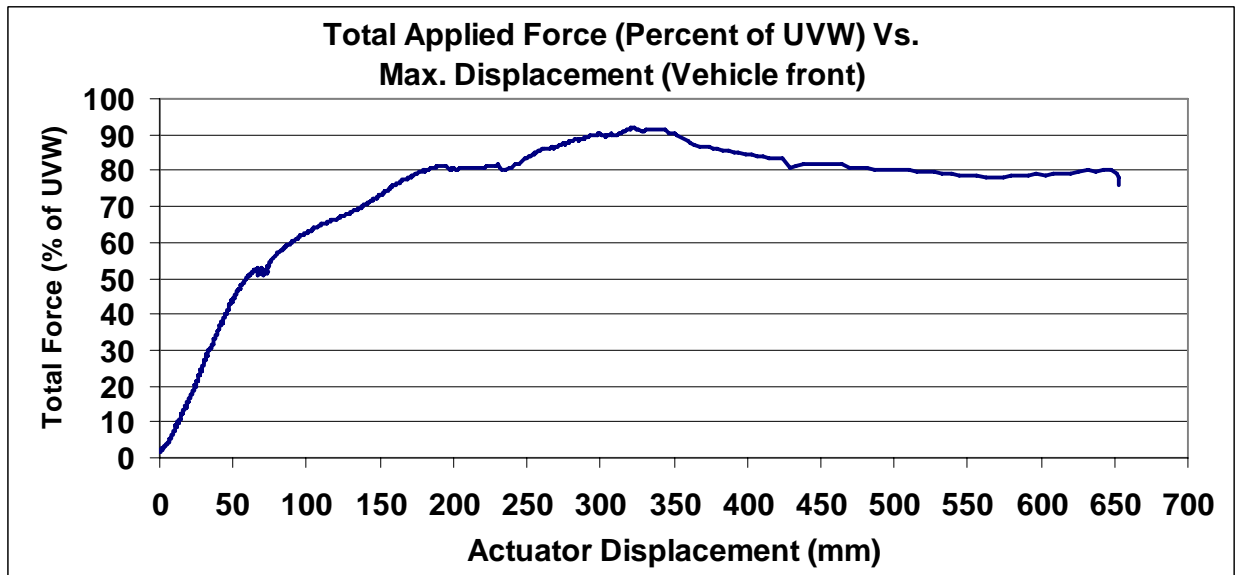


Figure 16: Applied Force in Percentage of Unloaded Vehicle Weight (UVW) vs Displacement

6.1.2 Prevost

A 2224 N (500 lbs) pre-load was applied evenly across the vehicle roof prior to the force application. The vertical movement of the force application plate relative to the load beams was

measured from this initial, pre-loaded condition. The roof loading was paused momentarily at a load of 0.5 x UVW in order to measure the forces required to operate the emergency exits. The side emergency exits windows were operable after application of the 0.5 x UVW was achieved. The loading was continued to a load of 1.0 x UVW and paused again. However, this time emergency exit operation was not performed because the vehicle roof continued to slowly yield during the 1.0 x UVW pause. Therefore, in the interest of test personnel safety, the emergency exit operation forces were not measured at this level. The loading was continued and the force application device reached its maximum displacement range before a load of 1.5 x UVW could be met. A peak load of 1.17 x UVW was achieved during the test. Approximately 12 seconds after the peak load was reached contact was made between the front residual space template and the left and right luggage racks. The test results are summarized in Table 6.

Table 6: Prevost FMVSS No. 220 Test Results

| | |
|--|--|
| Test UVW(1) | 13,381 kg (29,500 lb) |
| Calculated Target Maximum Roof Load = 1.5 x UVW(1) | 20,071 kg (44,245 lb) |
| Maximum Roof Load Achieved During the Test | 15,703 kg (34,619 lb) |
| Maximum Roof Deflection | 544 mm (21.42 in) |
| Residual Template Contact: | YES(2) |
| Emergency Exit Operation | The emergency exit windows were operable after the 0.5 UVW and after the test. No measurements were made at 1.0 UVW for safety reasons |
| Additional Test Observations: | Both front upper windshields (left and right) partially lost retention during the test. |

NOTE:

(1) This value was used for the maximum roof load calculation and is based on the UVW determined from the force application device, rounded up to 13,381 kg (29,500 lb).

(2) The left and right luggage racks contacted the foremost residual space template (T1) prior to reaching the calculated maximum roof load.

Figures 17 and 18 present the force and displacements of each of the four hydraulic actuators versus time. Note that the force applied by the four actuators is equal during the test by design to provide uniform loading on the roof. However, the displacement at the front of the bus is significantly greater than that at the rear of the bus. The total force applied is the sum of the forces from each actuator and the maximum displacement is that measured at the front of the bus. Figure 19 is a plot of the total applied force (presented as a percentage of the unloaded vehicle weight) versus the maximum actuator displacement.

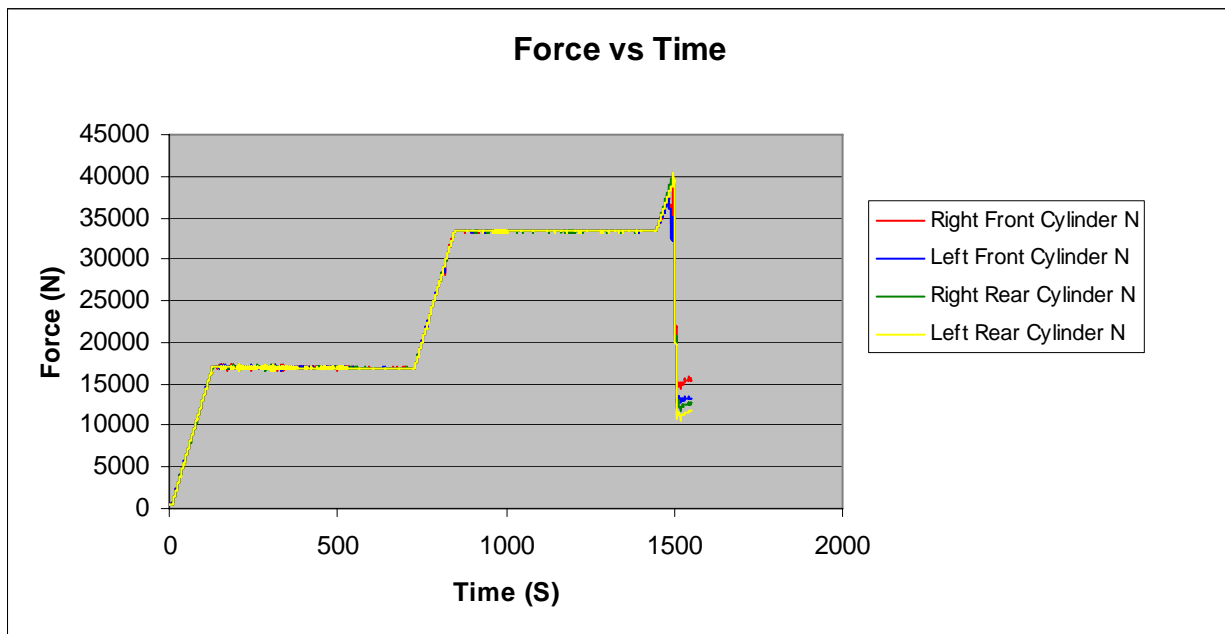


Figure 17: Actuator Force vs Time

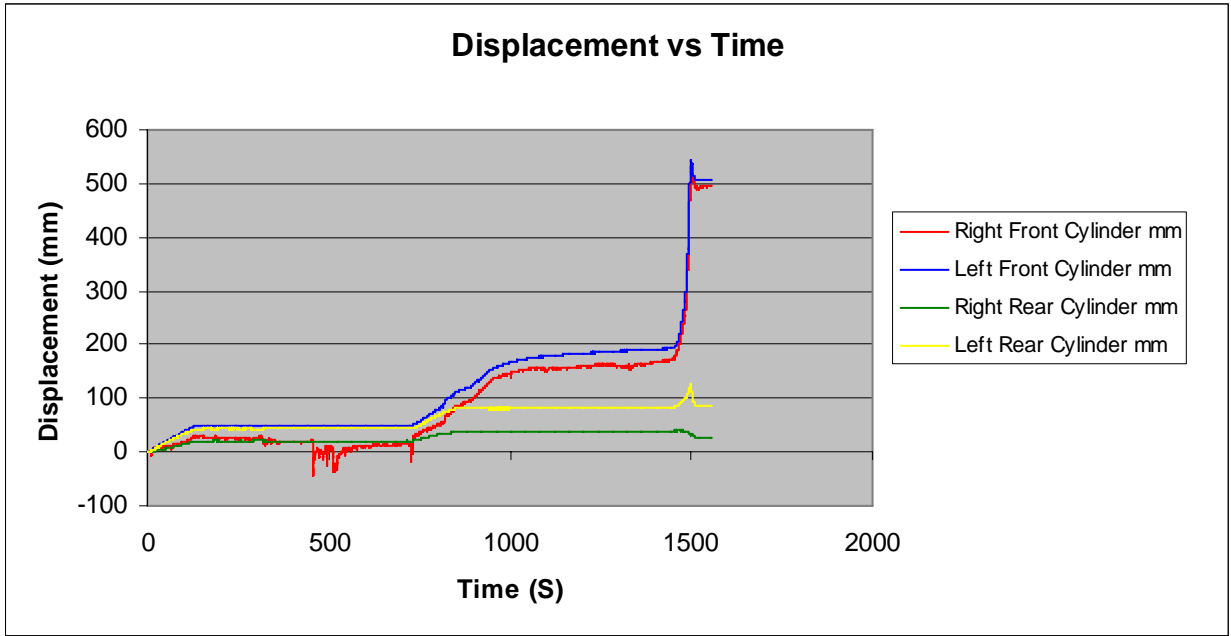


Figure 18: Actuator Displacement vs Time

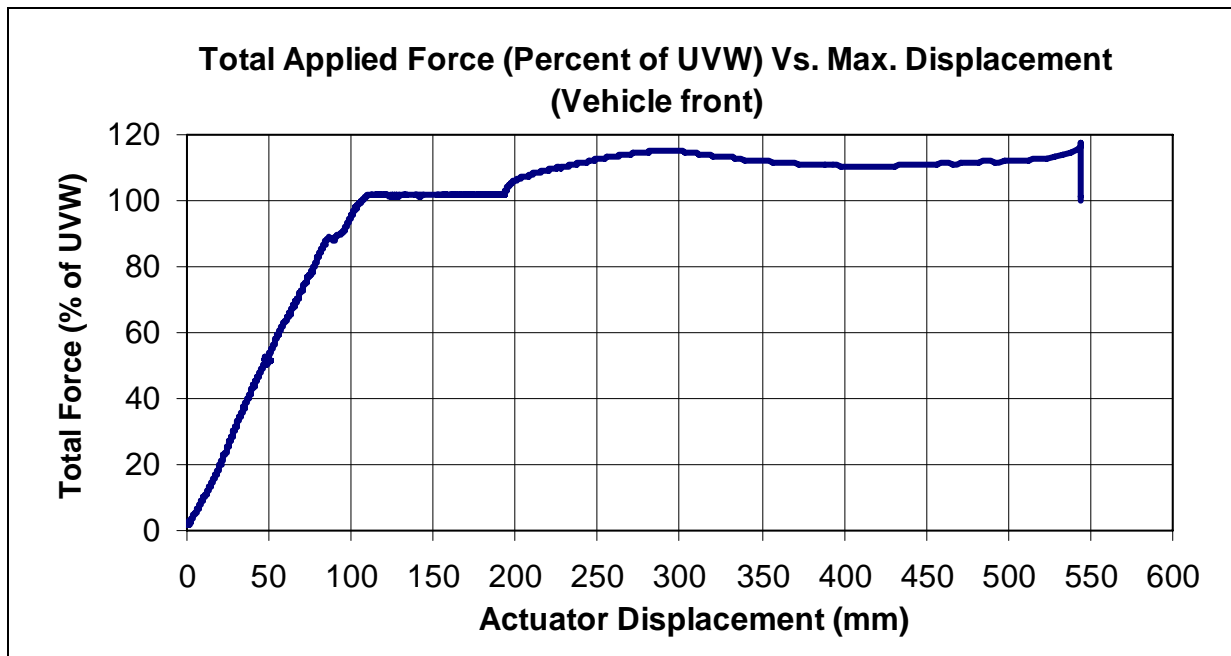


Figure 19: Applied Force in Percentage of Unloaded Vehicle Weight (UVW) vs Displacement

6.1.3 Analysis

The testing demonstrated that it is possible to apply the FMVSS No. 220 test to motorcoaches that are manufactured with the monocoque structure, with only minor modifications to the test device to facilitate mounting the bus to the test device.

Neither of the two buses tested were able to attain the 1.5 x UVW loading that is required according to the specifications in FMVSS No. 220 for school buses. The testing showed that the front sections of these two bus models are weaker than the back. This is most likely because the windshield and service door are located in the front of the bus and offer little resistance to the compressive load. Contact between the front residual space panel and luggage rack was made on both buses. The front of the MCI bus yielded to the compressive load at 0.91 x UVW, while the front of the Prevost bus yielded at 1.17 x UVW. One possible reason for the difference in the maximum yield load of the two buses is the number and size of the pillars between the front and rear of each bus. The MCI bus had seven pillars, 57 mm (2.24 in) wide, while the Prevost bus had 10 pillars, 205 mm (8.07 in) wide. While other properties such as material type, thickness, and shape play a role in compressive strength, the results show that the number of pillars also influences its ability to withstand a compressive load.

The side emergency exit windows on both buses were operable during and after the test.

6.2 ECE r.66

ECE r.66 based research tests were performed at MGA Research Corporation Proving Grounds in Burlington, Wisconsin, using a rollover platform fabricated by MGA according to the specifications in ECE-r.66, complete vehicle test. Occupant residual space templates were

constructed and installed in the front, middle, and rear of the passenger compartment. High speed video cameras and transfer media, applied to each residual space template, were used to determine if any portion of the vehicle interior had entered the occupant residual space during the rollover event. Variations from the base ECE-r.66 Annex 5 test included the following:

- The impact surface material was hard asphalt.
- The vehicle suspension was not fully blocked.
- Accelerometers were installed in the vehicle.
- Hybrid III 50th percentile Anthropomorphic Test Devices (ATD) were installed in the vehicle.

Accelerometers were installed in the vehicle occupant compartment within the same lateral planes as the residual space templates. At each template location, the accelerometers were mounted on the lateral centerline of the floor and on the impact-side interior corner of the roof. Two instrumented ATDs were included in each test. The first ATD was positioned on the right side of the bus on the aisle side of an OEM seat, with the armrest in the deployed position. The OEM seat was not equipped with restraints. A Freedman Seating Company bus seat with integrated lap/shoulder belt restraints and no armrest was installed in the location immediately behind the unrestrained dummy using the existing seat attachment points. The second ATD was placed in the aisle side position of the Freedman seat and was restrained. The ATD instrumentation consisted of 3-axis head, chest, and pelvis accelerometers as well as a 6-axis neck load cell. Chest compression was also monitored using a displacement potentiometer.

The motorcoach was positioned on the tilting platform with the driver's side (left) adjacent to the platform's hinge. The platform was raised at a steady rate of not more than 5 degrees/second until the vehicle reached its unstable equilibrium and commenced its roll, with the left upper edge of the vehicle making initial contact with the ground.

6.2.1 MCI

6.2.1.1 Vehicle Performance

The motorcoach was positioned on the tilting platform with the driver's side (left) adjacent to the platform's hinge. The platform was raised at a steady rate of not more than 5 degrees/second until the vehicle reached its unstable equilibrium when the platform was approximately 48 degrees from the horizontal and it commenced its roll. The bus then struck the ground near the left upper edge of the vehicle just above the windows. After the bus impacted the ground both sides of the windshield lost retention and fell from its supporting structure. Transfer marks showed that the front template struck the left side window (L1). During impact the emergency exit windows on the side opposite impact remained latched and the windows on the impact side remained intact but cracked. However, the emergency roof exit came open during the impact event. All left side luggage rack inboard hangers rearward of the front two hangers broke during the impact, leaving exposed sharp metal edges. Figure 20 presents a photograph of the bus being raised on the tilting platform. Post-test photographs of the bus are shown in Figures 21, 22 and 23. The test results are summarized in Table 7.



Figure 20: MCI Pretest photograph



Figure 21: MCI Post-test photograph front view



Figure 22: MCI Post-test photograph side view



Figure 23: MCI Post-test photograph front template transfer mark

Table 7: MCI r.66 Vehicle Test Results

| | Observation |
|------------------------------------|---|
| Impact Location: | Left upper edge of the bus. |
| Residual Space Template Contact: | <p>The left interior sidewall made contact with the front residual space template (T₁) leaving a transfer mark and cracks on window L1 and a transfer mark on the sidewall beneath window L1.</p> <p>There was no evidence of the interior contacting the middle (T₂) or rear (T₃) residual space templates.</p> |
| Additional Post-Test Observations: | <p>The arm rest at the unrestrained ATD location remained deployed and was bent slightly inboard. (The armrest was designed to lock in position.)</p> <p>Both front windshields sections (left and right) lost retention during the impact.</p> <p>The roof emergency exit opened during the impact. A gap was visible between the roof panel and the emergency exit frame.</p> <p>All left side luggage rack inboard hangers rearward of the front two hangers broke during the impact, leaving exposed sharp metal edges.</p> |

6.2.1.2 ATD Response

During the rollover event the restrained ATD was kept in its seat by the lap/shoulder belt restraint system and its left leg struck the aisle seat directly across from it. The unrestrained ATD slumped over the armrest into the aisle when the bus was raised on the tilting platform. It fell from this position when the bus struck the ground. All of the injury assessment values (IAV) were within acceptable limits with the exception of the Nij (compression-extension) which was 1.10. Figure 24 presents a pretest photograph of the ATDs positioned in the bus. Figures 25 and 26 present photographs of the ATDs in their final resting position. Table 8 presents observations to the ATD performance and Table 9 presents a summary of the IAVs for the ATDs.



Figure 24: MCI pretest ATD placement

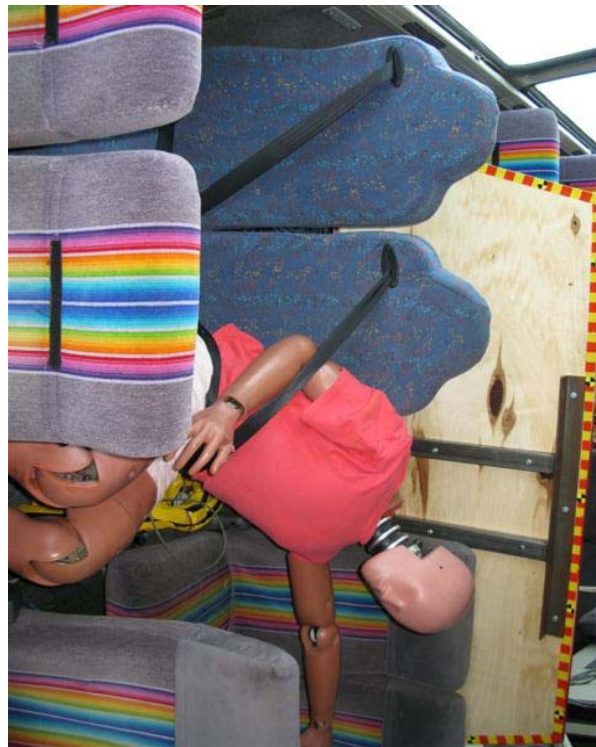


Figure 25: MCI post-test restrained ATD

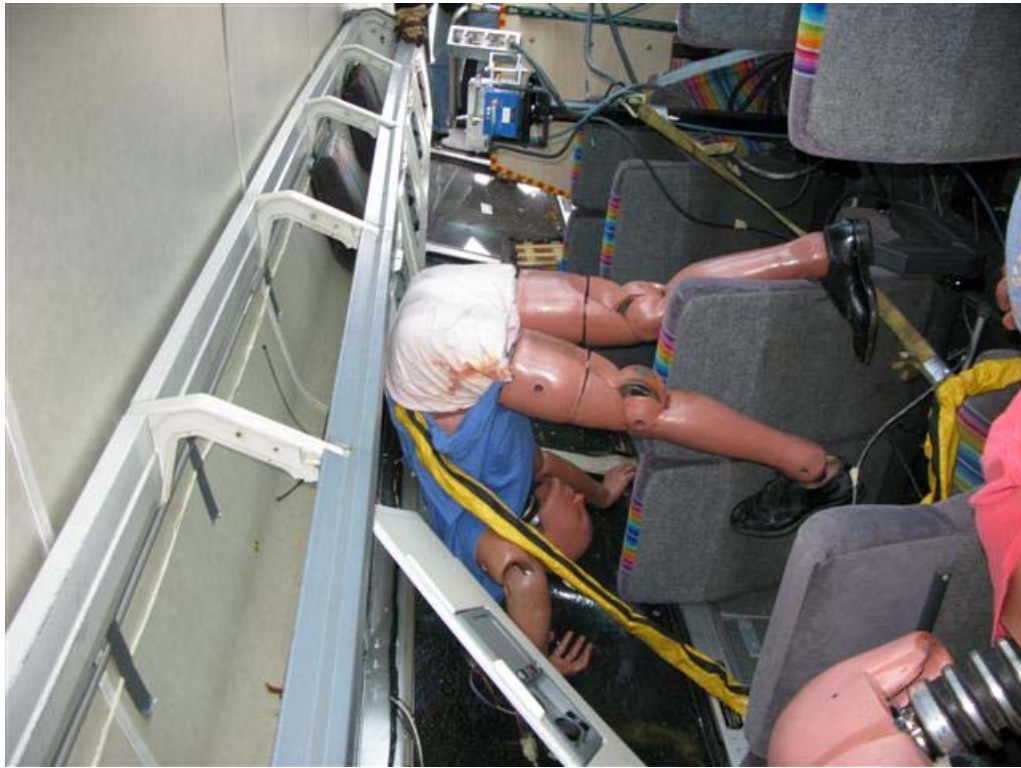


Figure 26: MCI post-test unrestrained ATD

Table 8: MCI r.66 ATD Performance

| ATD | Observation |
|---|--|
| Unrestrained ATD Contact: (in order of occurrence) | <p>Left side of the pelvis to the inboard armrest.</p> <p>Back of the head to the bottom of the left luggage rack.</p> <p>Back to the bottom of the left luggage rack.</p> <p>Top and back of the head to the left window.</p> |
| Restrained ATD Contact: (in order of occurrence) | Left knee to opposite side seat. |

Table 9: MCI r.66 IAVs

| Criteria Description | Threshold Value | Front Passenger (Unrestrained) | Rear Passenger (Restrained) |
|--|-----------------|--------------------------------|-----------------------------|
| Head Injury Measurements: | | | |
| Head Injury Criterion – 36ms interval (HIC-36) | 1000 | 18.6 | 2.2 |
| Head Injury Criterion – 15ms interval (HIC-15) | 700 | 18.6 | 1.0 |
| Neck Injury Measurements: | | | |
| Axial Tensile Force (N) | 4,170 | 182.4 | 250.6 |
| Axial Compressive Force (N) | -4,000 | -2945.0 | -51.4 |
| Nij (tension-flexion) | 1.0 | 0.03 | 0.04 |
| Nij (tension-extension) | 1.0 | 0.09 | 0.08 |
| Nij (compression-flexion) | 1.0 | 0.10 | 0.02 |
| Nij (compression-extension) | 1.0 | 1.10 | 0.01 |
| Thoracic Injury Measurements: | | | |
| Chest Acceleration (g) | 60 | 6.9 | 6.3 |
| Chest Compression (mm) | 63 | 4.3 | 0.9 |

6.2.1.3 Accelerometer Data

The data from the three tri-axial accelerometers that were mounted on the impact-side interior corner of the roof were filtered using a channel frequency class (CFC) 60 (100 Hz) digital filter. Figure 27 and Table 10 present the location of the accelerometers on the vehicle. Data plots of the X, Y and Z acceleration at each roof accelerometer location are presented in figures 28, 29 and 30. Figure 31 presents a data plot of the resultant roof accelerations at each template location. The peak accelerations for the Y and Z axis, the peak resultant acceleration, and average accelerations were calculated and are presented in Table 11. The average acceleration is the area under the resultant acceleration time history (from the start of deceleration until the resultant acceleration is effectively zero) divided by the associated time duration. The average acceleration along the top of the bus roof when the bus struck the ground surface is 7.59 g's (computed as the average of the average acceleration at each template location). The peak resultant roof acceleration is at the

foremost template and is equal to 63.5 g's. The average of the peak accelerations at the three templates is 58.3 g's.

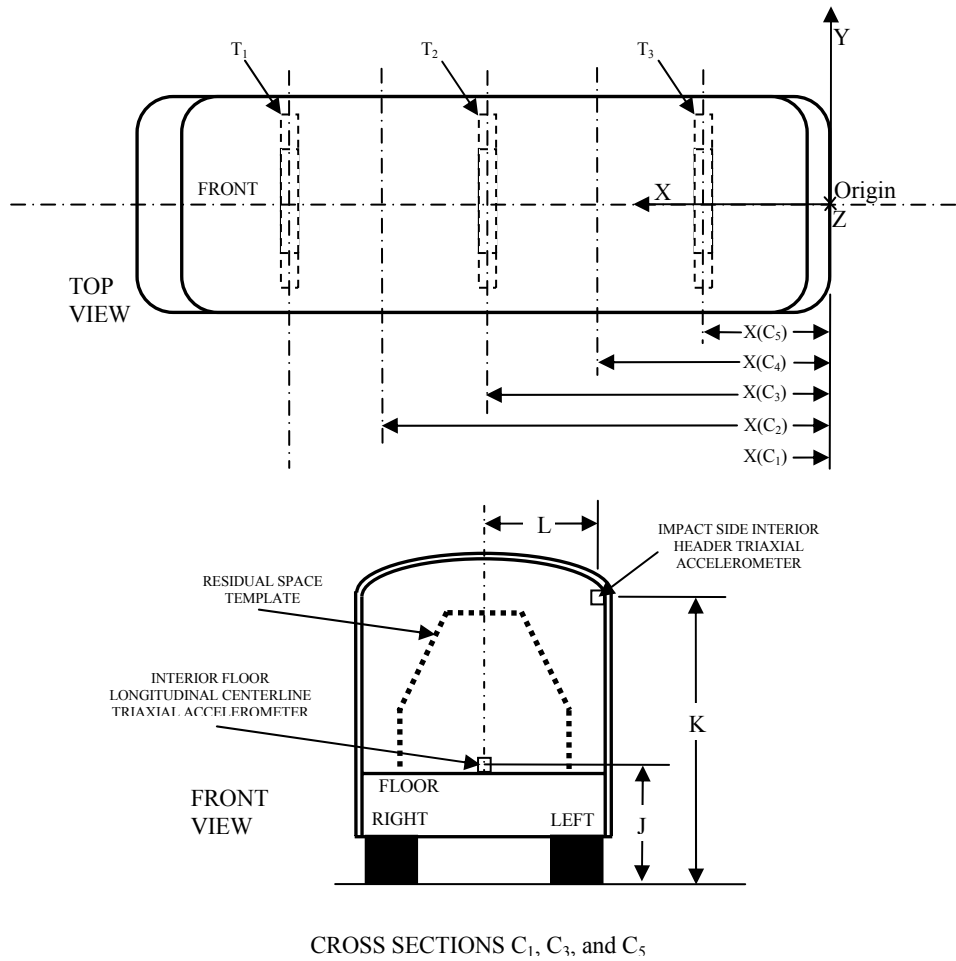


Figure 27: MCI Accelerometer Locations

Table 10: MCI Accelerometer Locations

| Cross Section | Accelerometers | Dimension (mm) | | |
|--|--|----------------|------|------|
| | | J | K | L |
| C₁ (Center of T₁) | Floor Longitudinal Centerline Triaxial and Impact Side Header Triaxial | 980 | 2917 | 1166 |
| C₃ (Center of T₂) | Floor Longitudinal Centerline Triaxial and Impact Side Header Triaxial | 1140 | 2923 | 1174 |
| C₅ (Center of T₃) | Floor Longitudinal Centerline Triaxial and Impact Side Header Triaxial | 1140 | 2950 | 1189 |

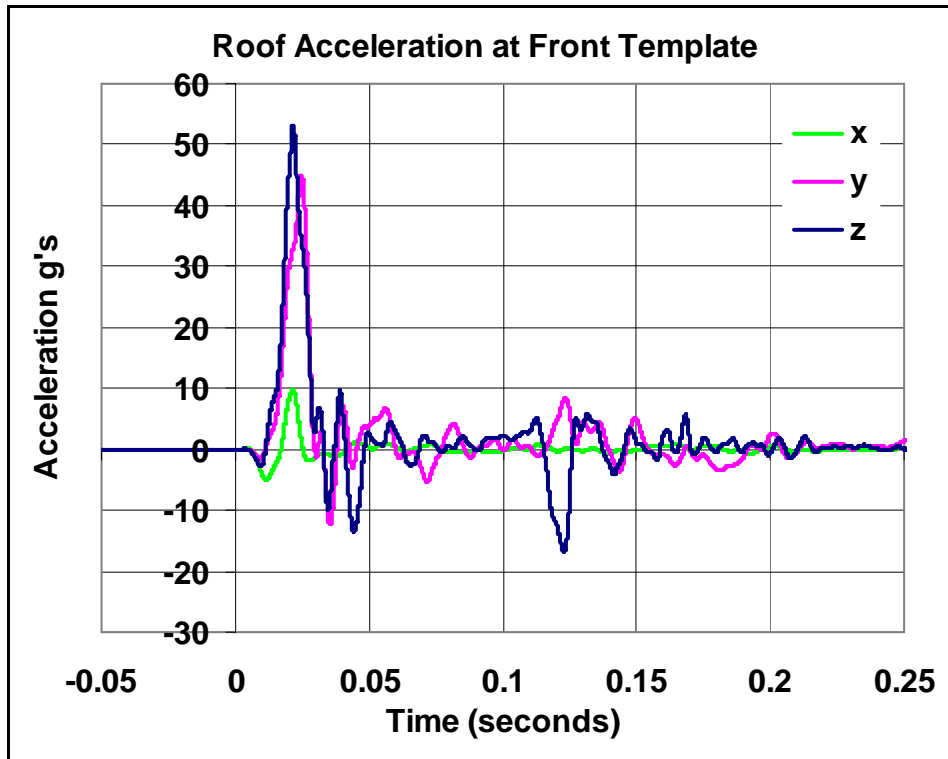


Figure 28: MCI Roof Acceleration at the Location of the Front Template

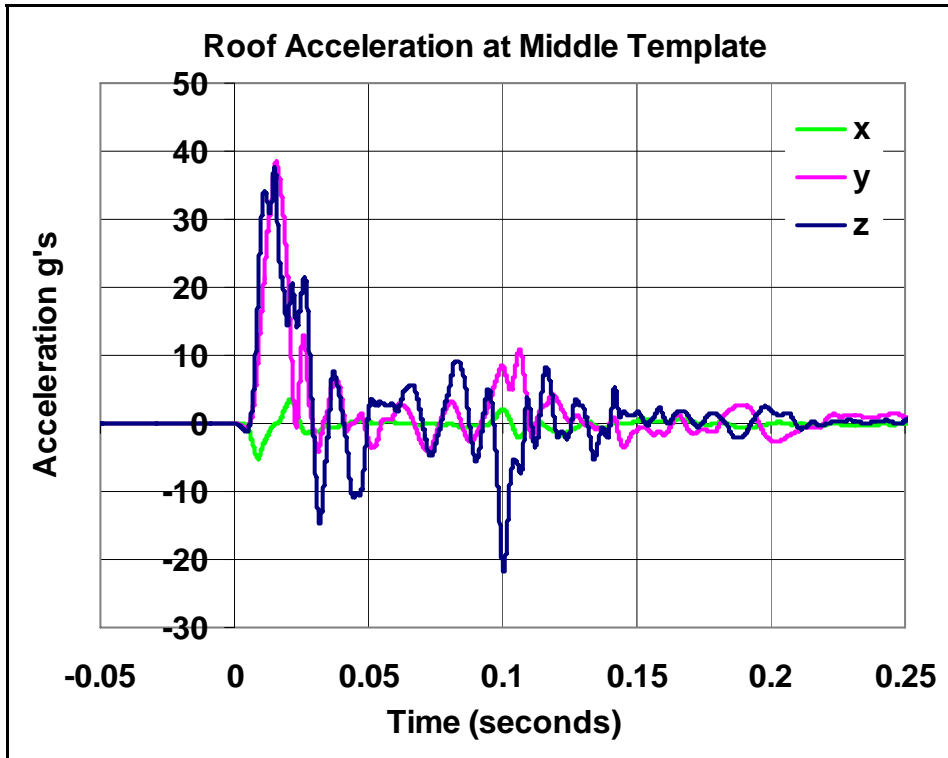


Figure 29: MCI Roof Acceleration at the Location of the Middle Template

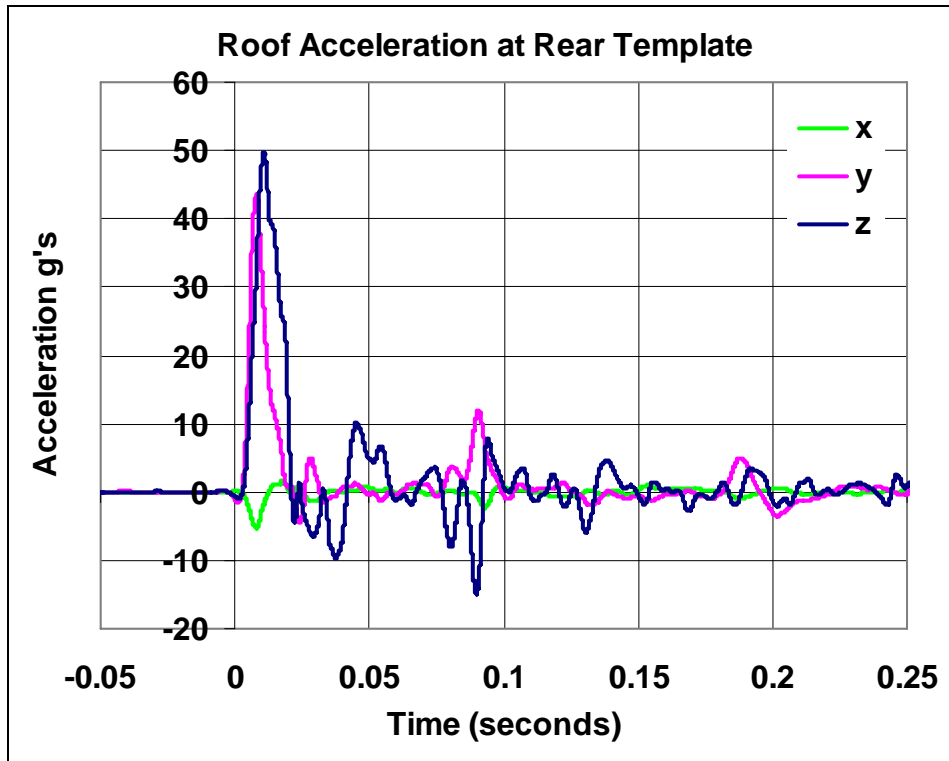


Figure 30: MCI Roof Acceleration at the Location of the Rear Template

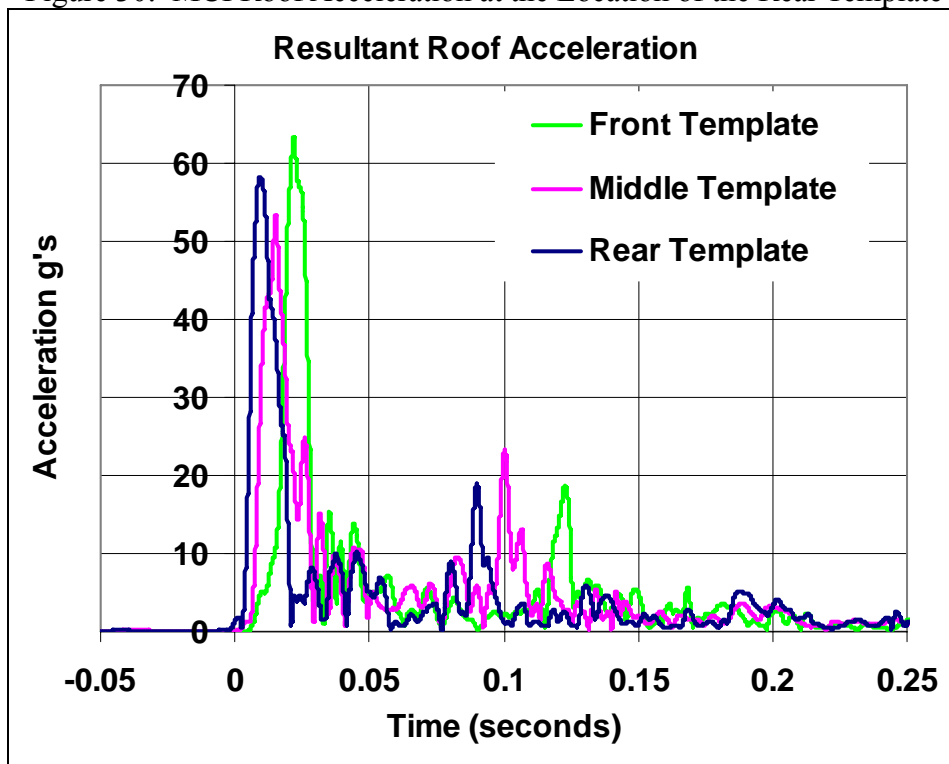


Figure 31: MCI Resultant Roof Accelerations at Front, Middle, and Rear Templates.

Table 11: MCI r.66 Roof Accelerations

| Location | Peak Y g's | Peak Z g's | Resultant g's | Average g's |
|-----------------------|-------------------|-------------------|----------------------|--------------------|
| Front Template | 44.97 | 53.23 | 63.45 | 7.81 |
| Mid Template | 38.48 | 37.59 | 53.34 | 7.95 |
| Rear Template | 43.52 | 49.71 | 58.23 | 7.00 |
| Average g's | | | | 7.59 |

6.2.2 Prevost

6.2.2.1 Vehicle Performance

The motorcoach was positioned on the rollover platform with the driver's side (left) adjacent to the platform's hinge. The platform was raised at a steady rate of not more than 5 degrees/second until the vehicle reached its unstable equilibrium when the platform was approximately 51 degrees from the horizontal and it commenced its roll. The bus then struck the ground near the left upper edge of the vehicle. After the bus impacted the ground both sides of the windshield lost retention and fell from its supporting structure. Transfer marks showed that the front template struck the sidewall beneath the left side window and the left side window (L1). During impact the emergency exit windows on the side opposite impact came unlatched and the windows on the impact side remained intact but cracked. However, the emergency roof exits came open during the impact event. The bus had two emergency roof exits both of which came open during the impact event. Most of the seats on the right side of the bus detached from their wall mounts. Figure 32 presents a photograph of the bus on the tilting platform. Post-test photographs of the bus are provided in Figures 33, 34 and 35. The test results are summarized in Table 12.



Figure 32: Prevost Pretest photograph



Figure 33: Prevost Post-test photograph front view



Figure 34: PrevoSt Post-test photograph side view



Figure 35: PrevoSt Post-test photograph front template transfer mark

Table 12: Prevost r.66 Vehicle Test Results

| Impact Location: | Left side of bus. |
|------------------------------------|--|
| Residual Space Template Contact: | <p>The left interior sidewall made contact with the front residual space template (T₁) leaving a transfer mark and cracks on window L1 and a transfer mark on the sidewall beneath window L1.</p> <p>There was no evidence of the interior contacting either the middle (T₂) or rear (T₃) residual space templates.</p> |
| Additional Post-Test Observations: | <p>The front windshields sections (left and right) lost retention during the impact.</p> <p>The roof emergency exits opened during the impact.</p> <p>Several emergency exit windows unlatched during the impact.</p> <p>Most of the seats on the right side of the bus detached from their wall mounts.</p> |

6.2.2.2 ATD Response

During the rollover event the restrained ATD was kept in its seat by the lap/shoulder belt restraint system. However, when the top of the bus impacted the ground the seat broke away from the sidewall and pedestal mounting to the bus structure. The unrestrained ATD slumped over the armrest into the aisle when the bus was raised on the tilting platform. It fell from this position when the bus struck the ground. All of the IAVs for the ATD restrained to the seat were within acceptable limits. The unrestrained ATD fell from its seat head first and struck its head on the window that separated it from the ground. The unrestrained ATD received unacceptable IAVs for the following:

- Head injury criterion (4,132)
- Neck axial compressive force (-17,732 N)
- Nij compression-flexion (2.85)
- Nij compression-extension (2.93)

Figure 36 presents a pretest photograph of the ATDs positioned in the bus. Figures 37 and 38 present photographs of the ATDs in their final resting position. Table 13 presents observations of the ATD performance and Table 14 presents a summary of the IAVs for the ATDs.



Figure 36: Prevost pretest ATD placement



Figure 37: Prevost post-test restrained ATD



Figure 38: Prevost post-test unrestrained ATD

Table 13: Prevost r.66 ATD Performance

| ATD | Observation |
|---|---|
| Unrestrained ATD Contact: (in order of occurrence) | Left side of the pelvis to the inboard arm rest. Top of the head to the left window. Back to the bottom of the left luggage rack. |
| Restrained ATD Contact: (in order of occurrence) | Knees to the left passenger seat. Top of head to the left sidewall. |

Table 14: Prevost r.66 IAVs

| Criteria Description | Threshold Value | Front Passenger (Unrestrained) | Rear Passenger (Restrained) |
|--|-----------------|-----------------------------------|--------------------------------|
| Head Injury Measurements: | | | |
| Head Injury Criterion – 36ms interval (HIC-36) | 1000 | 4132 | 10 |
| Head Injury Criterion – 15ms interval (HIC-15) | 700 | 4132 | 10 |
| Neck Injury Measurements: | | | |
| Axial Tensile Force (N) | 4,170 | 329 | 305 |
| Axial Compressive Force (N) | -4,000 | -17,732 | -1,474 |
| Nij (tension-flexion) | 1.0 | 0.06 | 0.02 |
| Nij (tension-extension) | 1.0 | 0.11 | 0.08 |
| Nij (compression-flexion) | 1.0 | 2.85 | 0.40 |
| Nij (compression-extension) | 1.0 | 2.93 | 0.12 |
| Thoracic Injury Measurements: | | | |
| Chest Acceleration (g) | 60 | 62 | 6 |
| Chest Compression (mm) | 63 | -1 | -1 |

6.2.2.3 Accelerometer Data

The data from the three tri-axial accelerometers that were mounted on the impact-side interior corner of the roof were filtered using a CFC 60 (100 Hz) digital filter. Figure 39 and Table 15 present the location of the accelerometers on the vehicle. Data plots of the X, Y and Z acceleration at each roof accelerometer location are presented in figures 40, 41 and 42. Figure 43

presents a data plot of the resultant roof accelerations at each template location. The peak accelerations for the Y and Z axis, the peak resultant acceleration, and average accelerations were calculated and are presented in Table 16. The average acceleration is the area under the resultant acceleration time history (from the start of deceleration until the resultant acceleration is effectively zero) divided by the associated time duration. The average acceleration along the top of the bus roof when the bus struck the ground surface is 8.20 g's (computed as the average of the average acceleration at each template location). The peak resultant roof acceleration is at the foremost template and is equal to 57.7 g's. The average of the peak accelerations at the three templates is 51.2 g's.

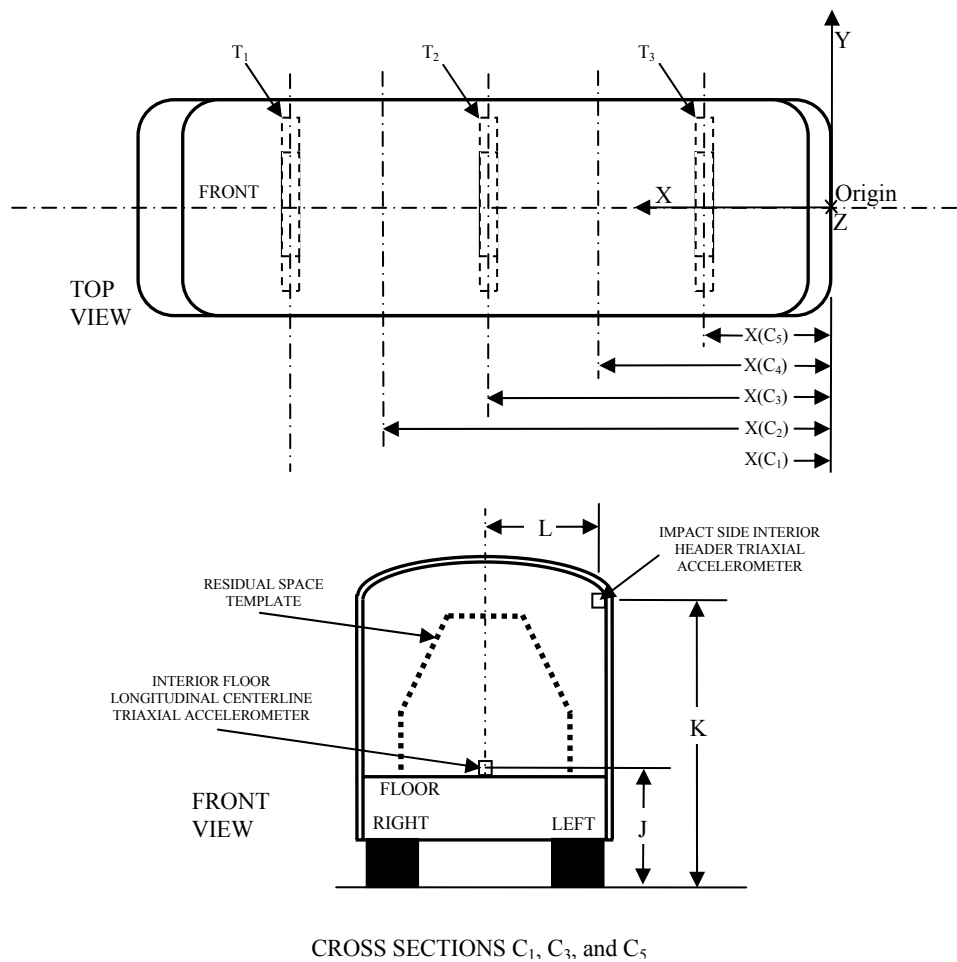


Figure 39: Prevost Accelerometer Locations

Table 15: Prevost Accelerometer Locations

| Cross Section | Accelerometers | Dimension (mm) | | |
|--|--|----------------|------|------|
| | | J | K | L |
| C ₁ (Center of T ₁) | Floor Longitudinal Centerline Triaxial and Impact Side Header Triaxial | 1141 | 2919 | 1215 |
| C ₃ (Center of T ₂) | Floor Longitudinal Centerline Triaxial and Impact Side Header Triaxial | 1141 | 2913 | 1242 |
| C ₅ (Center of T ₃) | Floor Longitudinal Centerline Triaxial and Impact Side Header Triaxial | 1141 | 2909 | 1225 |

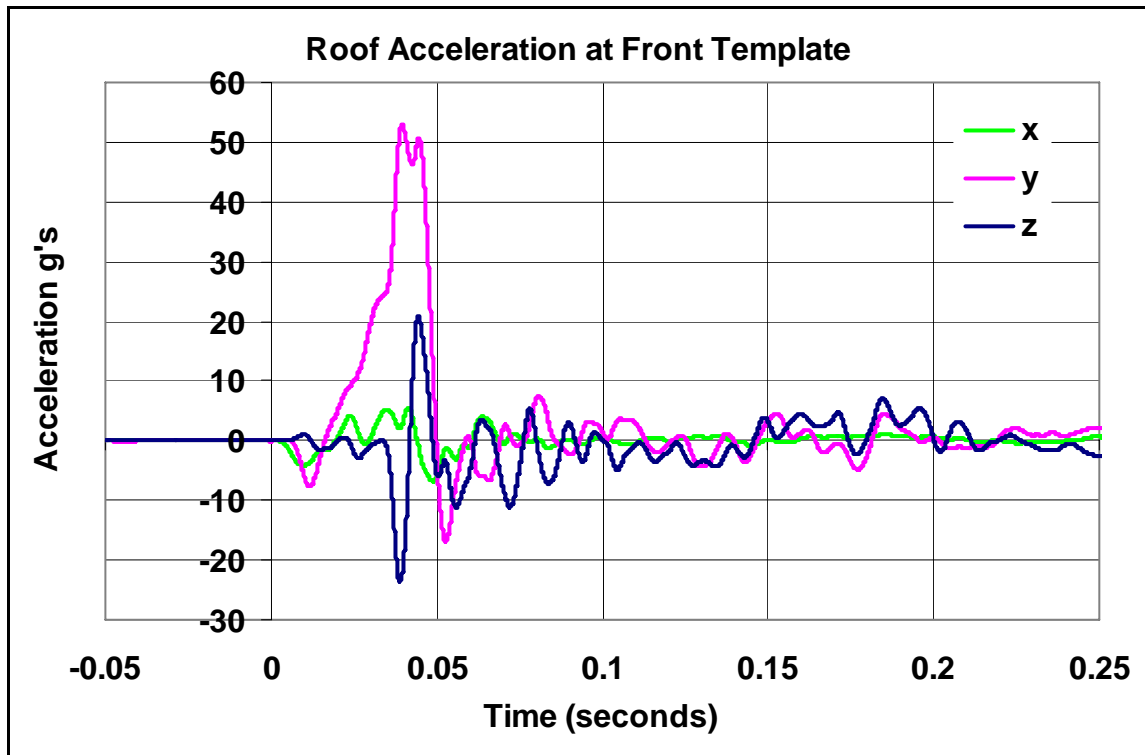


Figure 40: Prevost Roof Acceleration at Location of the Front Template

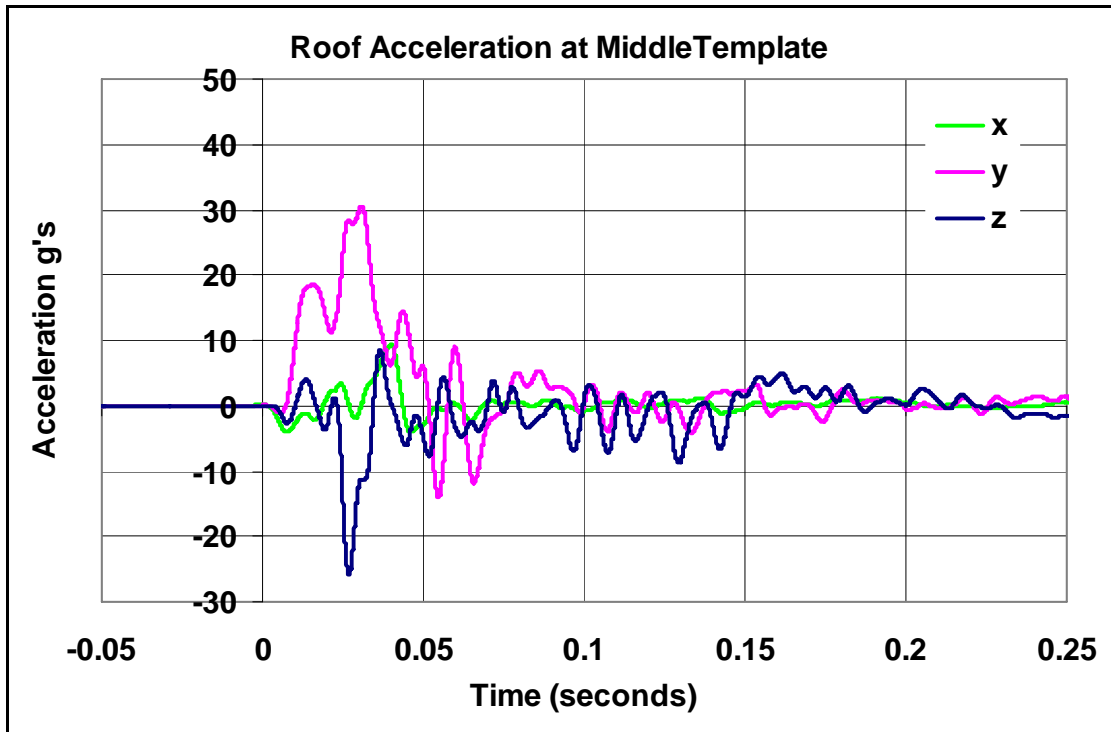


Figure 41: Prevost Roof Acceleration at Location of the Middle Template

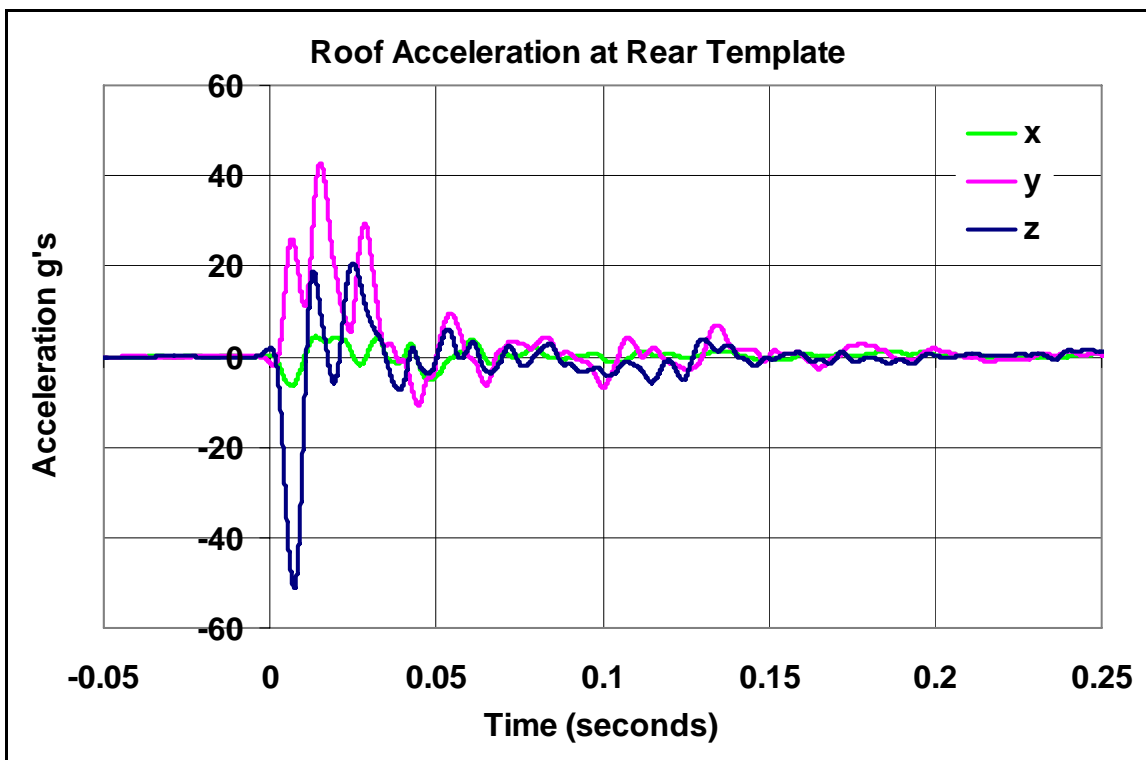


Figure 42: Prevost Roof Acceleration at Location of the Rear Template

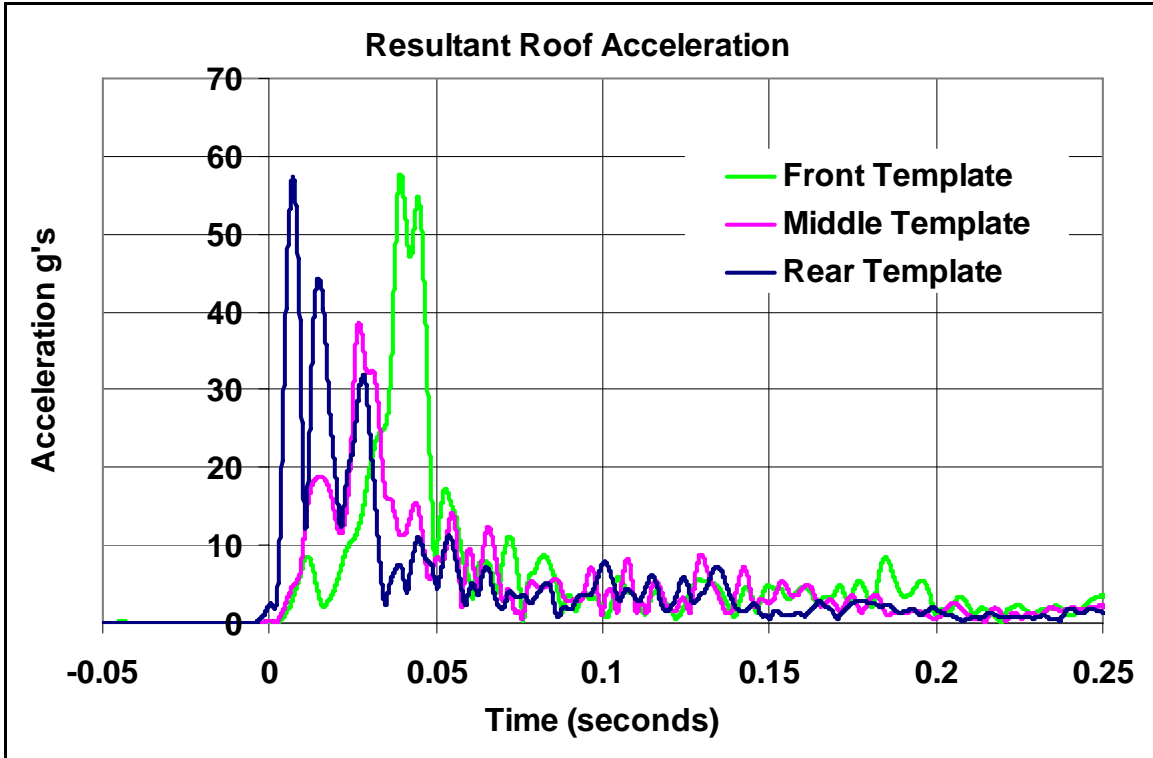


Figure 43: Prevost Resultant Roof Accelerations at the Front, Middle, and Rear Templates.

Table 16: Prevost r.66 Roof Accelerations

| Location | Peak Y g's | Peak Z g's | Resultant g's | Average g's |
|----------------|------------|------------|---------------|-------------|
| Front Template | 52.99 | -23.49 | 57.73 | 8.26 |
| Mid Template | 30.46 | -25.97 | 38.54 | 6.88 |
| Rear Template | 42.61 | -50.94 | 57.38 | 9.46 |
| Average g's | | | | 8.20 |

6.2.3 Analysis

The testing demonstrated that it is possible to apply the ECE r.66 complete vehicle test to motorcoaches. However, neither of the two buses tested was able to meet the residual space integrity requirement in the regulation. As in the FMVSS No. 220-based tests, the testing showed that the front of these two buses is weaker than the back. This is most likely because the

windshield and service door are in the front of the bus and offer little resistance to the impact with the ground. Contact between the front residual space template and left side window was made on both buses. On both buses the windows on the impact side remained intact but on the Prevost bus, the emergency exit windows on the side opposite impact came unlatched during the impact. On both buses the roof emergency exits opened when the roof of the bus impacted the ground. In actual rollover situations with passengers onboard, this may lead to unrestrained passengers being ejected from the bus, thereby increasing the risk of serious to fatal injuries.

The high speed video from both tests indicated that the side windows located on the far-side of the impact underwent a substantial amount of flexion during the impact with the ground but remained intact. The video also indicated that the side windows on the Prevost bus came unlatched and opened but closed when the bus came to its final resting position.

The performance of the ATDs restrained by the lap/shoulder belts, even with the seat in the Prevost bus that broke away from its side and floor anchorages, was adequate according to the IAVs measured. However, for the ATDs that were unrestrained, the type and severity of the injury indicated by the dummy IAVs depended on how they fell from their initial seated position during the rollover sequence. In the case of the MCI bus, the unrestrained ATD received only one IAV (Nij (compression-extension) 1.10) that was slightly over the acceptable limit. However, the results from the unrestrained ATD in the Prevost bus, where the ATD fell across the bus head first on to the side window which was in contact with the ground, resulted in multiple IAVs that were well above the acceptable limits. The response of the ATDs in the rollover testing indicates riding unrestrained could result in some passengers receiving serious to fatal injuries depending on how they fall across the bus. However, if all passengers were restrained, those on the far-side of the

impact would have a lower risk of sustaining injuries from the rollover event. No predictions about the injury outcome can be made for those passengers on the impact side because the two tests conducted with the MCI and Prevost buses did not have any ATDs on that side.

Average accelerations from the roof accelerometers when the buses impacted the ground ranged from 7.59 to 8.2 g's. These average acceleration values agree very well with the Transport Canada simulation study that indicated average roof acceleration of 7.6 g's on a 13,420 mm (44 ft) Prevost bus. One difference in the accelerometer data that was observed in the MCI and the Prevost bus test, was the direction of the Z-axis acceleration. The acceleration data indicated that when the bus first struck the ground, the Z acceleration was negative (pointed upward from the bus floor) and quickly went positive as the bus deformed and rolled. However, on the MCI bus all the Z accelerations were positive meaning the vector pointed down from the top of the bus towards the bus floor. One possible explanation for this difference is the location of the accelerometers on the bus with respect to the impact location. Each of the buses had the accelerometers located just above the windows. The windows on the MCI bus did not curve into the roof and the MCI bus had a smaller radius of curvature between the sidewall and the roof than the Prevost bus. The Prevost bus had windows that curved and projected into the roof with a larger radius of curvature between the sidewall and the roof. This put the accelerometer in front of the impact location, whereas the location of the accelerometers on the MCI bus was near or just below the impact location. This indicates that the direction of the initial impact force would depend on where the bus struck the ground with respect to the roof and any flexing of the attachment location with respect to the accelerometer location.

6.3 Comparison of FMVSS No. 220 and ECE r.66 Test Methods

6.3.1 FMVSS No. 220

FMVSS No. 220 places a uniformly distributed vertical force pushing directly downward on the top of the bus with a platen that is 914 mm (36 inches) wide and that is 305 mm (12 inches) shorter than the length of the bus roof. While this type of force application is not indicative of the typical forces that buses undergo in a rollover situation, school buses complying to the FMVSS No. 220 specifications have performed very well in real world rollover events with very little racking⁹ of the sides. This may be because in order to comply with the specifications in FMVSS No. 220 requires not only strengthening of the roof structure but also the strengthening the entire bus frame, including the sides and associated joints. It is also possible that school bus manufacturers have engineered their buses to withstand the type and direction of forces that occur in rollovers. It should be noted that some States require an additional racking test on the sides of the school buses to ensure that the sides of the school buses do not collapse during the rollover type event. The limit on the travel of the platen in the FMVSS No. 220 test ensures that there is adequate survival space for the occupants of the bus.

6.3.2 ECE r.66 Complete Vehicle Test

ECE r.66 complete vehicle rollover test creates a force near the top corner of the bus in the transition from the sidewall to the roof. This force is more representative of a bus rolling over into a drainage ditch along a highway without a lateral or longitudinal vehicle velocity. However, in the ECE r.66 test the bus strikes a hard surface that is more rigid than the typical earthen drainage ditches along the roadside. The hard surface ensures that the energy from the rollover is

⁹ The tilting of the sides of the bus relative to the bus floor

absorbed by the bus and not shared between the bus and the ground. The required templates inside to the bus ensure that there is adequate survival space for the bus occupants.

6.3.3 ECE r.66 Body Section and Quasi-Static Tests

The Rollover Test of Body Sections Representative of the Vehicle and Quasi-Static Loading Tests of Body Sections test methods allowed in ECE r.66 were not included in this testing program.

Each of these methods requires a section of the bus body instead of the complete vehicle. Buses are not built in sections but are unibody which will make it difficult to obtain standalone body sections. A cutout of a body section from a complete vehicle may significantly alter the load distribution in the body section compared to the full vehicle. In addition, testing with body sections deviates from the way that NHTSA normally does compliance testing. For school buses and other motor vehicles, NHTSA purchases the complete vehicle for compliance testing. This ensures that NHTSA uses test vehicles that are representative of what is being sold for use on the highways. To utilize this option NHTSA would have to purchase stand alone body sections from the manufacturers. However, testing with these body sections will not account for variability in material and manufacturing processes and so may not be an accurate representation of the performance of the vehicles in the fleet.

6.3.4 ECE r.66 Computer Simulation

The methods of certification by using quasi-static calculations based on testing of components and computer simulation (finite element analysis) of complete vehicle also were not included in this testing program. Each of these methods requires a thorough knowledge of the material properties, structural design and manufacturing process, that is only available to the manufacturer. These methods typically are used by the manufacturer during the design phase of new motor vehicles,

eliminating the need to build many different prototype vehicles for testing purposes. However, these methods cannot take into account any differences that may occur because of variation in material properties and manufacturing processes. Enforcement using computer simulations would be difficult and is not currently used in any regulatory test procedure at NHTSA.

6.3.5 FMVSS No. 220 and ECE r.66 Energy Analysis

In an effort to quantitatively assess the relative stringency between the FMVSS No 220 and the ECE r.66 tests with the MCI and Prevost buses, a review of the energy absorbed by the buses in each of the two tests was examined.

Since the bus contacted hard asphalt surface (does not deform) in the ECE r.66 test, the change in potential energy of the bus when it tips from the tilting platform can be assumed to have been absorbed by the bus to deform it. The change in potential energy in the ECE r.66 test is the product of the mass of the bus in kg, the gravitational acceleration (9.81 m/sec^2), and the change in height of the center of gravity (CG) of the bus (in meters) from the time just before it tips off the tilting platform to the time when the roof contacts the ground. While the test facility did not have the capability to determine the location of the CG of the bus, an estimate was made from the video as the bus tipped from the tilting platform. The total energy absorbed in the FMVSS No. 220 test was obtained by adding the area under the force-deflection curves for each of the four force actuators.

Table 17 presents the energy absorbed by the MCI and Prevost buses in the FMVSS No. 220 and ECE r.66 tests and Figures 44 and 45 present the total energy absorbed as a function of maximum measured displacement in the FMVSS No. 220 tests with the MCI and Prevost buses.

The energy absorbed by the two buses in the ECE r.66 test is 2.5 to 3 times greater than that at maximum applied load in the FMVSS No. 220 test. However, since the ECE r.66 test is a dynamic event while the FMVSS No. 220 test is a quasi-static event and since the load applications in the two tests are significantly different, the absorbed energy cannot be directly compared.

Both the buses experienced vertical displacement of the platen that exceeded the maximum allowable level of 130 mm (5 1/8 inches) in the FMVSS No. 220 tests. Additionally, both buses crushed into the ECE r.66 survivable space templates in both the FMVSS No. 220 and the ECE r.66 tests. Since both the buses failed to comply with the FMVSS No. 220 and ECE r.66 requirements, it is not possible to objectively assess the relative stringency of these two tests with the available information.

Table 17: FMVSS No.220 and ECE r.66 Energy Analysis

| | Mass (kg) | Energy at 130 mm crush (J) | Energy at Maximum Achievable Load | | ECE r.66 Potential Energy (m*g*Δh) | |
|---------|-----------|----------------------------|-----------------------------------|--------|------------------------------------|------------|
| | | | UVW | (J) | CG Δh (m) | Energy (J) |
| MCI | 12,700 | 4,444 | 0.91 | 33,960 | 0.840 | 104,653 |
| Prevost | 13,381 | 7,140 | 1.17 | 37,599 | 0.723 | 94,906 |

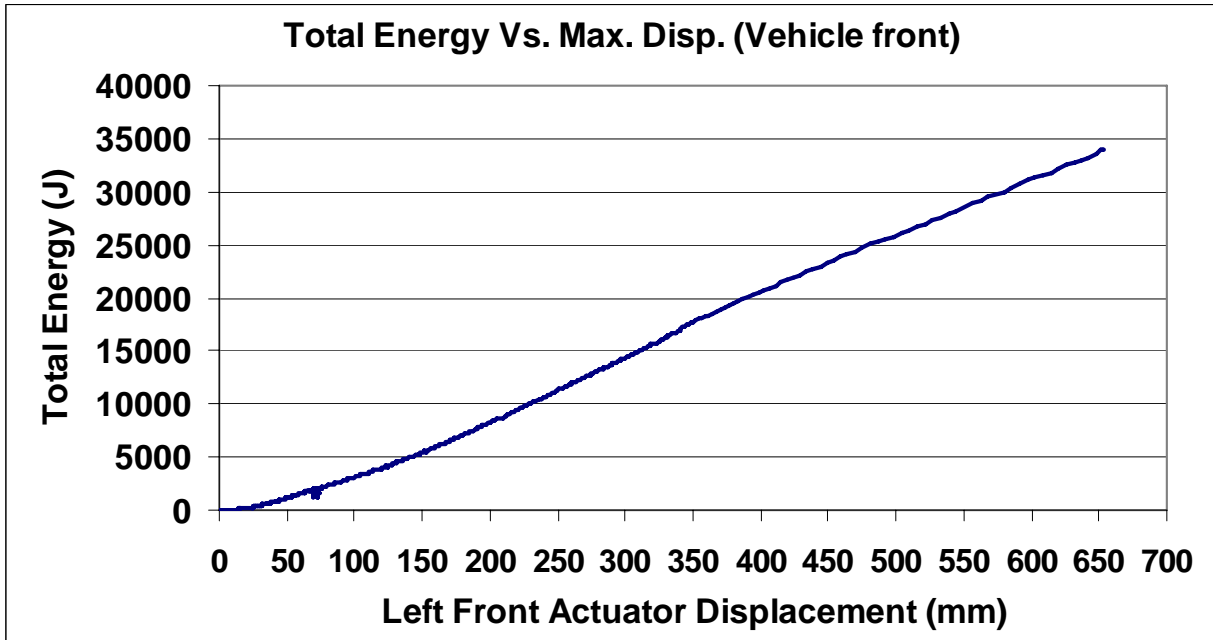


Figure 44: Energy Absorbed in FMVSS No. 220 Test with MCI Bus

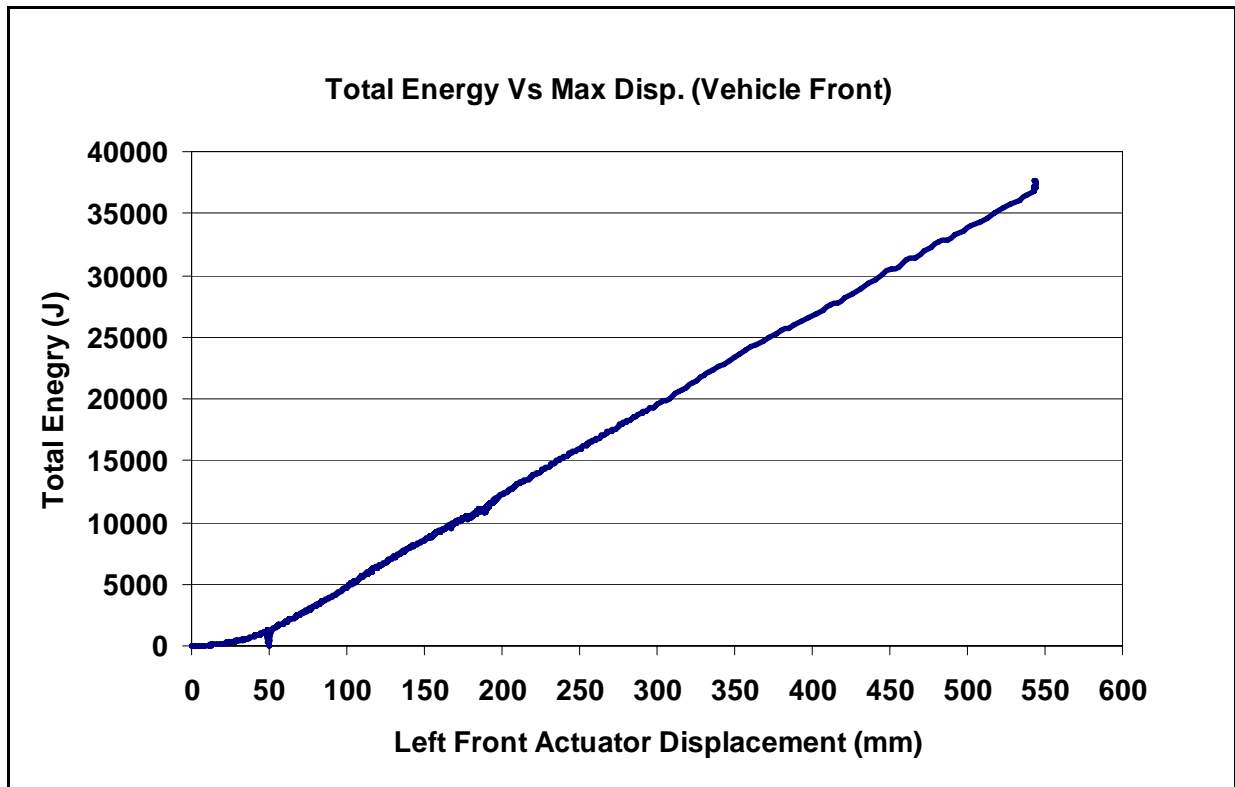


Figure 45: Energy Absorbed in FMVSS No. 220 Test with Prevost Bus

6.3.6 FMVSS No. 220 and ECE r.66 Qualitative Analysis

While it was not possible to quantitatively assess the relative stringency between FMVSS No. 220 and ECE r.66, it is possible to perform a qualitative assessment. From a qualitative basis it appears that the FMVSS No. 220 criteria for school buses may be more stringent than the rollover requirements in ECE r.66 for roof structural integrity. This is based on the observation that neither of these buses was able to support its UVW in the FMVSS No. 220 tests and failed catastrophically prior to reaching the 1 ½ times UVW. Both of the buses crushed the approximately 355 mm (14 in) of vertical distance between the top of the ECE r.66 survivable space template and the luggage rack. The MCI bus reached the 130 mm (5.118 in) maximum displacement criteria for school buses at approximately 70 percent of UVW, and the Prevost bus reached the 130 mm (5.118 in) displacement limit at a load equal to the UVW and continued to yield beyond that limit.

During the ECE r.66 rollover tests only the front residual space templates struck the side windows in both the MCI and Prevost buses. The imprints indicate that only the lateral corner of the templates struck the side window. This suggests that with design changes to counteract the lateral forces in the rollover incidents these buses could pass the ECE r.66 rollover tests. Based on the above observations, it appears that the FMVSS No. 220 test protocol may be more stringent than the ECE r.66 test protocol for evaluating roof crush.

All the emergency exits remained operable during and after the FMVSS No. 220 tests, while in the ECE r.66 tests the far side emergency exit windows opened on the Prevost bus and the emergency roof exits on both the MCI and the Prevost buses came open. Therefore, the ECE r.66 test protocol is better for evaluating the integrity of the emergency exits during rollover incidents.

7.0 Options for Future Considerations

Based on the testing it appears that either the FMVSS No. 220 or the ECE r.66 test protocols can be used for developing an FMVSS that applies to motorcoach rollover protection. The testing demonstrated that with only minor modification to the equipment at the test facility, both test procedures were adaptable to the 12,200 mm (40 feet) motorcoaches tested in the program. However, consideration needs to be given on the testing of the newer and larger motorcoaches that are 13,725 mm (45 feet) in length.

Both the FMVSS No. 220 and the ECE r.66 tests indicate that the front section of the bus is the weakest part of the bus body. This maybe because both the windshield and the front service door are located in this area. Also, some of the newer buses are equipped with wheelchair access doors, typically located near the rear of the bus on the right side, which could further weaken the sides of the buses. This should not pose a problem with testing to either of the test protocols but manufacturers would need to provide adequate reinforcement in these areas to meet the FMVSS No. 220 or the ECE r.66 complete vehicle rollover test requirements.

7.1 FMVSS No. 220 Type Test Procedure

A test procedure similar to the one in FMVSS No. 220 could be adopted for motorcoaches but consideration should be made for testing the longer 13,725 mm (45 feet) motorcoaches. In order to test the longer 13,725 mm (45 feet) motorcoaches modifications may need to be made to the existing test devices to accommodate the longer bus length and modifications may need to be made to the hydraulic system that applies the uniformly distributed load across the length of the bus to accommodate the increased weight. The current hydraulic systems raise the bus from the bottom into the platen at the top of the bus. This type of system requires the hydraulic actuators to

be sized correctly to the weight distribution of each bus to ensure that the load to the top of the bus is evenly distributed as required by the regulation.

As stated earlier, manufacturers would need to reinforce bus body structure to meet the 1.5 x UVW loading required in FMVSS No. 220 or the standard could be set at a lower level provided a study was done to show that a lower level would provide adequate safety. However, based on the current testing, the 1.5 x UVW load specification should not be hard to achieve if the front section of the buses were reinforced to provide additional support.

7.2 ECE r.66 Complete Vehicle Test Procedure

A test procedure similar to the one in ECE r.66 complete vehicle test could be adopted for motorcoaches but consideration should be made for testing the longer 45 foot motorcoaches. NHTSA is not aware of any of the existing test facilities that is capable of testing motorcoaches 13,725 mm (45 feet) in length. In order to test the longer 13,725 mm (45 feet) motorcoaches modifications to existing devices would need to be made to accommodate the longer bus length and weight. Because the device needed to perform the ECE r.66 test is just a raised platform, the cost of building a new test device should be minimal.

As in the FMVSS No. 220 type test, manufacturers would need to reinforce bus body structure to meet the requirement in ECE r.66 for survivable space. The results of the rollover test of the two 12,200 mm (40 feet) motorcoaches indicate that the front section of the motorcoach would need to be reinforced to provide additional support for lateral strength to meet these requirements.

8.0 Conclusions

The testing demonstrated that either test protocol is practicable for testing motorcoaches built with monocoque construction. The testing also showed that the Prevost bus with smaller windows and larger roof pillars withstood a higher load because of its construction. Qualitatively, the FMVSS No. 220 test protocol appears to be more stringent for roof collapse but the ECE r.66 complete vehicle test is more representative of real world rollover. In addition, ECE r.66 appears to be a better protocol for determining if emergency exits remain closed during rollover.