LARGE SCHOOL BUS SAFETY RESTRAINT EVALUATION - PHASE II

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ABSTRACT

This paper details the National Highway Traffic Safety Administration's (NHTSA) continuing research and testing activities on large school bus safety restraints. This paper will discuss relative performance of compartmentalization, lap belt restraints and lap/shoulder belt restraints, as well as the effects of seat back height and seat spacing on the performance of these safety restraint strategies. Results of NHTSA's frontal sled testing efforts with an inflatable airbag belt system are reviewed. The agency's efforts on researching side impact protection are also briefly discussed. This paper supplements the results presented in the 17th Enhanced Safety of Vehicles Conference (ESV), Paper No. 345, "Large School Bus Safety Evaluation" [1], and discusses results for tests that were conducted subsequent to the publication of that paper.

INTRODUCTION

As discussed in 17th ESV Paper No. 345 [1], NHTSA's school bus safety restraint research program consisted of three phases: (1) defining the extent of the problem, (2) conduct of both a frontal and side impact full-scale dynamic crash test with large school buses, and (3) conduct of a series of sled tests to evaluate various school bus restraint alternatives. This paper will only discuss the results from Phase 3: sled test evaluation of compartmentalization, lap belts, laps/shoulder belts and inflatable airbag belt restraints. Phases 1 and 2 are discussed in the 17th ESV paper.

PHASE III-SLED TESTING AND VALIDATION

Figure 1 is a plot overlay showing the decceleration pulse of the vehicle's center of gravity (CG) accelerometer from the frontal rigid barrier crash test with an acceleration plot of a sled test simulation of the crash. As can be seen, the sled's acceleration pulse is a good replication of the acceleration time history of the full-scale frontal impact test. The leveling off of the acceleration pulse of the crash test from about 40-90 ms is a result of the bus body sliding along the chassis. The somewhat higher acceleration profile of the sled during this time resulted in a slightly higher velocity change (delta-v) for the sled tests when compared to the crash test.

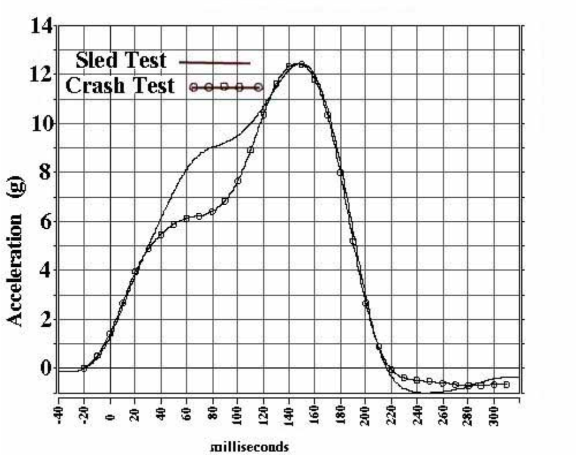

Figure 1. Crash Test and Sled Test Pulses.

Over the course of testing, two different sled bucks were used to evaluate the various bus safety restraint systems. The first sled buck was fabricated from a section of a bus body. This allowed assessment of the degree of deformation/energy absorption by the bus floor and the potential for occupant interaction with any portion of the bus interior other than the seats. Figure 2 is a photograph of this sled buck. The body section contained three rows of seats, with seats mounted on both the right and left side of the center aisle, which allowed for testing a potential maximum of 2 rows (or 4 seats) per test.

Testing with this sled buck showed that there was no significant interaction between the dummies and the interior walls or ceiling of the bus in a full frontal crash. There was incremental deformation to the floor of the bus shell with repeated testing, but the amount of deformation was minimal for any single test. The amount of impact energy associated with this deformation of the bus floor was an insignificant portion of the total absorbed by the seat.

Figure 2 - First (Full Shell) Sled Buck.

The second sled buck utilized a rigid floor of 1.3 cm (0.5 in) thick aluminum plate with an open frame construction. Figure 3 is a photograph of the modified sled buck used in subsequent sled tests. This design provided for a more durable, and thus a more consistent, test platform. It also allowed for better mounting of the high speed digital imaging hardware, resulting in more complete analysis of the dummies kinematics and their interaction with the seats and safety restraint systems.

Figure 3 - Second (Open Frame) Sled Buck

Sled Test Parameters

The initial test matrix was designed to focus on three test parameters for evaluation:

1. Occupant size
2. Restraint strategies
3. Loading conditions (from unrestrained occupants)

This matrix was subsequently expanded to assess the additional factors of:

4. Seat spacing
5. Seat back height

Three occupant sizes were used to evaluate the various restraint strategies:

1. **Average 6-year-old**: represented by the Hybrid III 6-year-old dummy at 114 cm / 23.6 kg (44.9 in / 52 lb) with seated height of 63.5 cm (25.0”).
2. **Average 12-year-old**: represented by the Hybrid III 5th percentile female dummy at 150 cm / 49 kg (59 in / 108 lb), with seated height of 78.7 cm (31.0”).
3. **Large high school student**: represented by the Hybrid III 50th percentile adult male dummy at 175 cm / 78 kg (69 in / 172 lb) with seated height of 88.4 cm (34.8”).

Three different restraint strategies were initially evaluated using this test matrix. Late in the testing program, two additional restraint systems became available for evaluation. These additional restraint systems were subjected to an abbreviated test matrix comparable to the first three restraint systems. The initial restraint systems were:

1. **Compartmentalization**
2. **Lap belt** (with compartmentalization)
3. **Lap/shoulder belts** on a bus seat with modified seatback

The two additional restraint systems were:

1. **Lap/shoulder belt** with compliant seat back
2. **Inflatable airbag lap belt**

Three different loading conditions were simulated during the sled testing:

1. Restrained occupants (with no loading from occupants seated behind them)
2. Restrained occupants with rear loading (from unrestrained occupants seated behind them)
3. Unrestrained occupants (into the seat-back positioned in front of them).

Testing was conducted using three different seat spacings. The seat spacing was determined by measuring from the H-point[1] of the SAE 3-dimensional machine (OSCAR) to the back of the seat (measured at the same vertical height of the H-point) located in front of the dummy. The seat spacing values selected for these tests were 48 cm

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[1] Mechanically hinged hip point simulating the actual pivot center of the human torso and thigh

(19 in), 56 cm (22 in), and 61 cm (24 in). These values were selected based on information obtained from the FMVSS 222 compliance tests. Review of these data showed seat spacing ranging from 41 cm (16 in) to 61 cm (24 in), with most falling between 48 cm and 56 cm (19 in and 22 in). FMVSS 222 allows a maximum seat spacing of 61 cm (24 in), while 48 cm (19in) was found to be the practical minimum for normal seating of a Hybrid III 50th percentile adult male dummy. The third seat spacing of 56 cm (22 in) effectively spanned the most common range of seat spacing observed in the available data.

The current minimum seat back height required under FMVSS No. 222 is 50.8 cm (20 in) from the seating reference point (SRP)[2]. A seat design option offered by seat manufacturers, and required in several states, is a "high back" design where the seat back height is typically 61 cm (24 in) above the SRP. The higher seat back design was a necessity for the lap/shoulder belt strategies tested, in order to provide an anchor point for the shoulder belt portion of the restraint systems. In addition to the lap/shoulder belt seat designs, a number of standard seats with the "high back" option were obtained from BlueBird and the C.E.White Co. and included in the test program.

Injury and Kinematics Evaluation

The motion of the occupant in the seat, and its interaction with the seat back and seat restraints, are important factors in determining the type, mechanism, and potential severity of any resulting injury. Analysis of the dummy kinematics was useful in evaluating a restraint system's performance and determining its potential for preventing, or causing, injury.

In addition to dummy kinematics, various injury assessment criteria were used to assess the restraint systems. All of these criteria were calculated as specified in the Interim Final Rule for FMVSS 208 "Occupant Protection." The neck injury criterion, N_{ij}, is calculated from moment and axial loads on the neck in a frontal impact. The criterion value is normalized to a pass/fail value of 1.0, which represents a 22 percent risk of serious neck injury. HIC_{15} is a 15 ms acceleration based criterion used to assess the risk of head injury. The pass/fail threshold limit of 700 represents a 30 percent risk of serious head injury. Finally, the Chest G is based on a 3 ms duration resultant acceleration with a pass/fail criterion threshold limit of 60 g's, which represents a 20 percent risk of serious chest injury.

Compartmentalization - Figure 4 is a plot of the resultant head accelerations (used to calculate HIC_{15}) of a compartmentalized seat test for a 6-year-old and 5th percentile adult female dummy. Figure 5 is a plot of the neck injury criterion (Nij) for the same test.

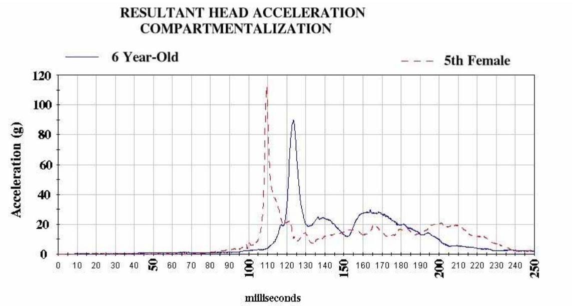

Figure 4 - Resultant Head Acceleration

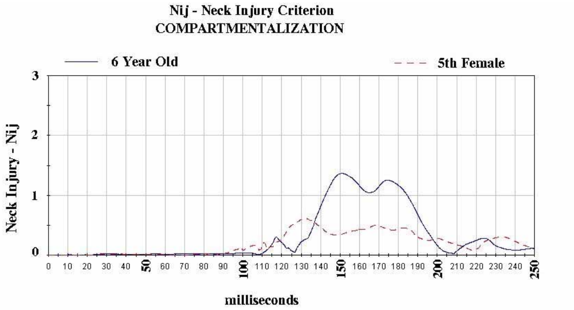

Figure 5 – Neck Injury Criterion (N_{ij})

Figures 6, 7, 8 and 9 illustrate the typical sequence of events that occur in a frontal crash for a passenger in a compartmentalized seat. For this particular test, seat spacing was 48 cm (19 in) with impact into a high back seat design configuration. No dummies were seated rearward of subject occupants.

The dummies were initially seated in a normal, upright position on the seat bench with the back of each dummy situated against the seat back (see Figure 6). The dummies were positioned laterally by designating the seat as having outboard (wall side) and inboard (aisle side) seating positions and centering the dummy on the corresponding side.

During the initial moments of the crash, the dummies slid forward on the seat while maintaining their upright posture. This continued until the lower extremities or knees struck the seat back in front of the seated dummy (See Figure 7).

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[2] Manufacturer's design reference point simulating the position of the center of pivot of the human torso and thigh.

Figure 6. Compartmentalization at 0 ms.

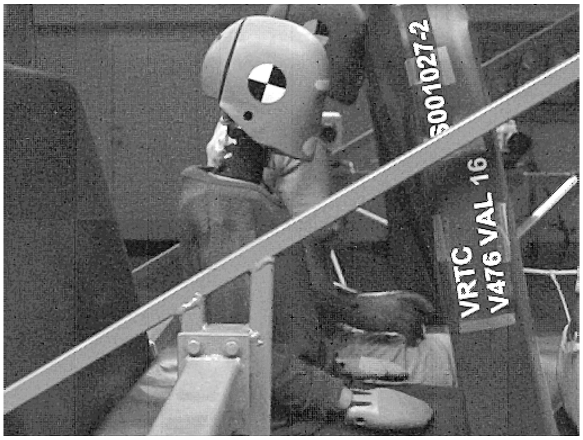


Figure 7. Compartmentalization at 100 msec.

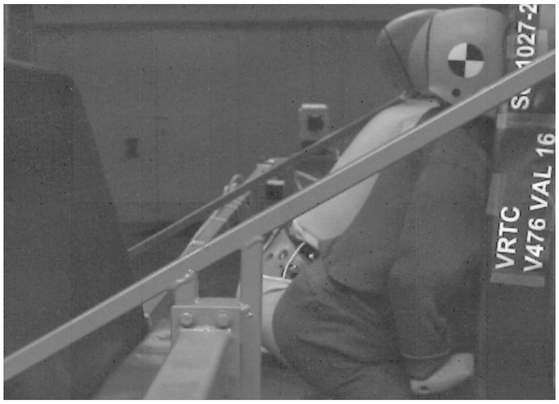


Figure 8. Compartmentalization at 150 ms.

Figure 9. Compartmentalization at 210 msec.

At this point, the torso rotated forward and downward causing the head to strike the seat back. The 5th percentile female showed a peak head acceleration at approximately 110 ms, with the 6-year-old striking shortly later in the event with a peak acceleration occurring around 123 ms. These accelerations generated HIC_{15} values of 207 and 250, respectively.

As the torso continued to rotate forward, the head was forced rearward by the seat back placing a moment load on the neck. Figure 8 is an image taken at 150 ms into the crash event. The shoulders of both dummies had come into contact with the seat back. This limited the degree of extension, and to some extent, the amount of loading placed on the neck.

As the dummies continued to slide forward on the seat bench, the upper torso continued to flatten out against the seat back, thereby reducing loading on the neck. By 210 ms (Figure 9) the chest had come into full contact with the seat back, relieving the load on the neck and allowing the Nij values to drop.

Lap Belt Restraints - The lap belted dummy had an initial motion similar to that of the compartmentalized restrained dummy. The dummy began its motion by sliding forward on the seat bench until the slack in the restraint system was taken up. At this point, the pelvic region was restrained while the head and torso continued forward and rotated downward into the seat back situated in front of the dummy.

Figures 10 and 11 show the resultant head accelerations and Nij plots of the dummy in lap belt restraint system. The initial head impact (148 ms) produced a load on the neck of the 6-year-old dummy. The dummy kinematics and resulting neck and head injury values were similar to those seen in the compartmentalization tests. However, as the upper body continued to pivot at the hips and rotate forward and down into the seat back, subsequent loading on the neck occurred. This can be seen as a second peak in the Nij values that occurred well after the initial head impact (at approximately 175 ms).

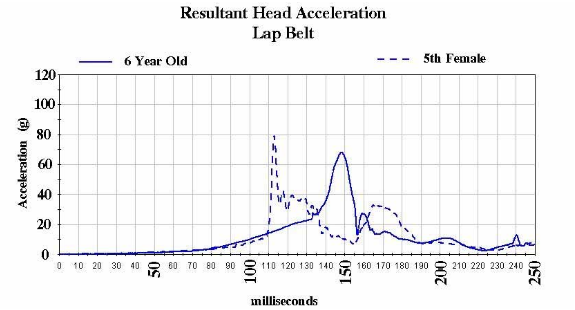


Figure 10. Resultant Head Acceleration for Lap Belt Restraint.

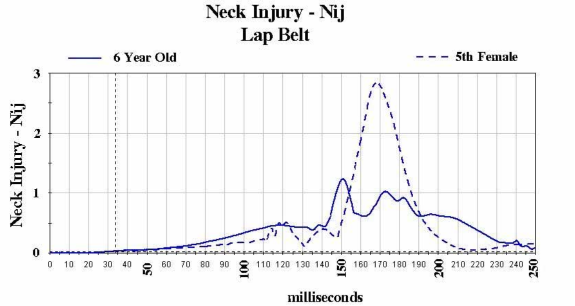


Figure 11. Neck Injury Criterion (N_{ij}) for Lap Belt Restraint.

By contrast, the neck loading for the 5th percentile female dummy at the point of head impact was relatively low. As the torso continued to rotate forward, the loading on the neck became much higher. Figure 12 is an image taken 150 ms into the test. The relative degree of extension can be observed for the two dummies. Interaction of the chest and shoulders with the seat back was restricted by the lap belt. As the torso rotated forward, the energy of this momentum was absorbed by the neck as it was forced into extension, rather than by impact of the chest and shoulders into the seat back. Under these kinematic conditions, the 6-year-old dummy was subjected to a significant neck load, while the 5th percentile female dummy was subjected to a much higher neck loading by the same torso rotation.

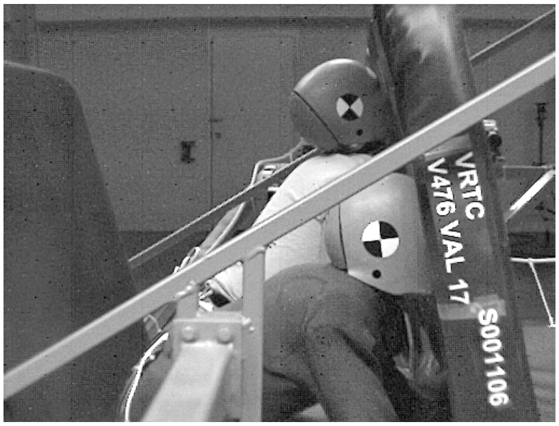


Figure 12. Lap Belt Restraint System at 150 ms.

The Nij response for a dummy using a lap belt restraint system appears to be sensitive to the motion and orientation of the dummy's torso, which in turn is affected by dummy stature and seat spacing. Since the upper body is not restrained or prevented by the lap belt from fully interacting with the seat back, it is possible for an extreme degree of neck loading to occur.

<u>Lap/Shoulder Belt Restraint</u> - The seat back structures were modified to accommodate the additional loading on the seat back due to occupant(s) loading the shoulder belt upper anchorage points for both the production school bus seats manufactured by Bus Belt and a prototype seat design developed by the C.E.White Co. These designs still allow the seat back to deflect within the force deflection corridor specified in FMVSS 222. At a pre-determined point in the deflection range the seat back becomes structurally more rigid, limiting the degree of total deflection and maintaining the compartmentalized frontal barrier (for occupants rear of the lap/shoulder belt outfitted seat). Lap/shoulder belt systems restrain the upper body, preventing or significantly reducing the velocity of head impact into the seat back, which in turn reduces moment loading on the neck and significantly reduces the neck injury criterion (Nij) values.

The lap/shoulder belt restraint systems are sometimes misused. Two common misuse scenarios that occur were tested during this program: "misuse 1" – shoulder belt portion of the system placed behind the back of the dummy, and "misuse 2" – shoulder belt portion of the system placed under the dummy's arm. With the belt placed behind the back (misuse 1), the restraint system essentially became a lap belt system with test results very similar to those observed with the lap belt systems. When the shoulder belt was positioned under the arm (misuse 2), the shoulder belt crossed low across the torso of the dummy which tended to rotate the upper body of the dummy before impact into the seat back This torso rotation tended to confound the Nij results, which are correlated to measure a pure frontal loading condition.

Figure 13 is an image taken at the peak Nij loading, 168 ms into the event, showing the neck at its maximum flexion. The maximum injury criteria values for this type of restraint, when correctly worn, typically occurred when the upper torso was stopped by the shoulder restraint and the head and neck were snapped forward from the inertial energy. The resulting head accelerations and neck loadings were relatively low with this type of restraint.

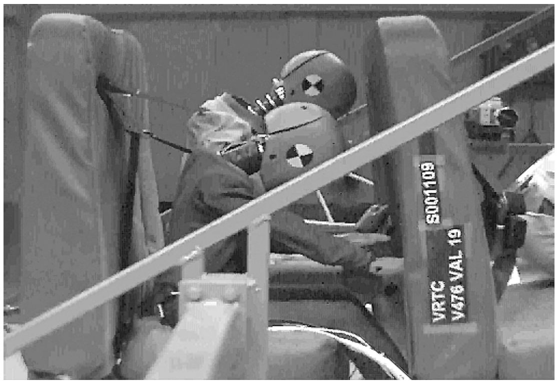


Figure 13. C.E.White Lap/Shoulder Belt Restraint System at 168 ms.

A potential issue raised by the installation of lap/shoulder belt restraint systems is the additional loading that is placed on the seat back by the shoulder anchor portion of the restraint system. The inertial loading due to the torso of a restrained passenger can increase the amount of forward deflection of the seat back, significantly reducing its ability to safely restrain (via compartmentalization) an unbelted passenger seated behind a lap/shoulder belt restrained passenger. Current regulations require that safety restraint systems maintain the ability to provide passive protection or restraint (compartmentalization in bus seat design) to the vehicle's occupants. Increasing the structural strength of the seat back can address this problem, but the additional rigidity of the seat back may present a potential risk of increased injury to the "unrestrained" passenger. This could be particularly significant if the seat forward of the passenger is unoccupied since the seat back, with no additional torso loading to help deflect the seat back upon impact, may be overly rigid for effective passive protection.

Initial sled tests indicated that the stiffer seat backs of these designs could increase the HIC_{15} injury criterion significantly for the unbelted passenger. The C.E.White Co. provided a second prototype seat design with modified foam padding in the seat back that significantly lowered the HIC_{15} values in subsequent testing. A second lap/shoulder belt design strategy to address this seat back issue was developed by Indiana Mills Manufacturing Inc. (IMMI). This seat design isolated the shoulder belt anchor points from the seat back by creating a second, or "inner", frame used to anchor the restraint system. Figure 14 is an image of a sled test of the IMMI seat. The inner seat back frame can be seen in this image as it was pulled away from the "outer" frame of the seat back by the torso loading of the restrained dummies, as it is designed to do. The "outer" frame remained in position to provide a padded impact surface for the two unbelted 50th percentile adult male dummies seated behind the restrained dummies in this test.

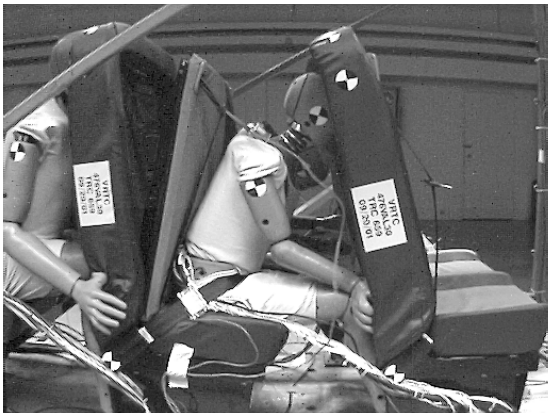


Figure 14. IMMI Lap/Shoulder Belt Restraint System.

Lap Belt Air Bag Restraint - A final safety restraint design tested in this program was developed by AMSAFE. The restraint, which was originally developed for use in commercial passenger aircrafts, utilizes an airbag system incorporated into a lap belt restraint. Figure 15 is an image taken at 50 ms showing the initial deployment from the lap belt. The airbag expands outward from the passenger's lap into the space between the passenger and the seat back forward of the seated position.

Figure 16 shows the airbag at full deployment. The airbag cushioned and prevented head impact into the

Figure 15. AMSAFE Airbag Lap Belt Restraint System at 50 ms.

Figure 16. AMSAFE Airbag Lap Belt Restraint System at Full Deployment.

seat back while supporting the head to reduce loading on the neck. This resulted in low HIC_{15} and Nij values, which were similar in magnitude to those seen in the lap/shoulder belt restraint tests. Although results were similar between the two restraint systems, testing of the airbag lap belt restraint system was very limited and did not include testing of possible misuse, or out of position, scenarios to determine possible disbenefits of the system.

Discussion of Results

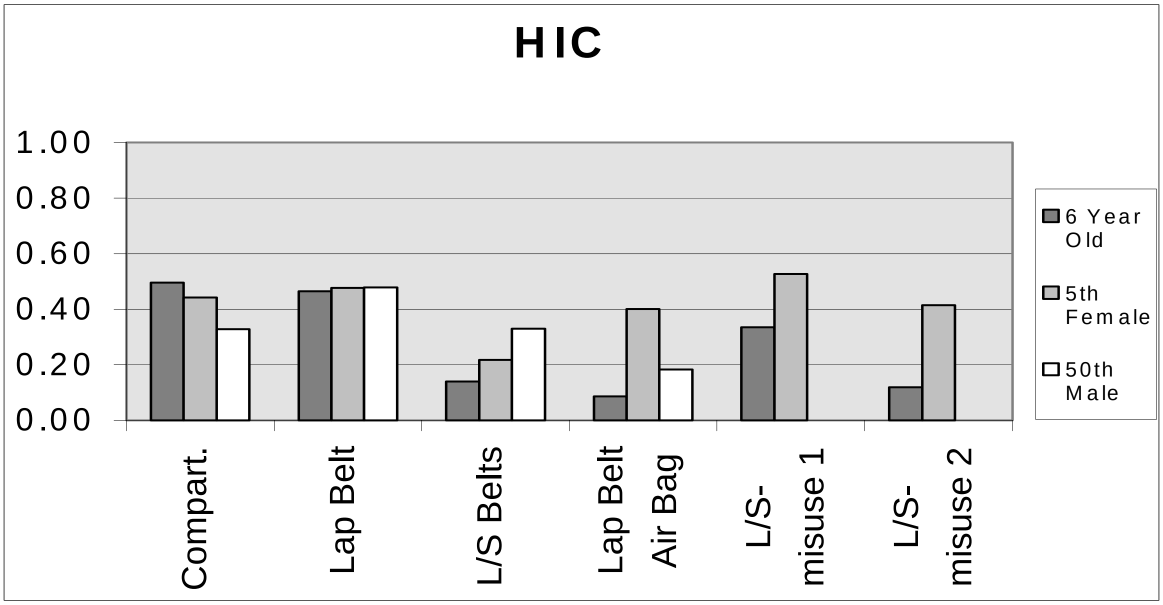
The data presented in the following figures represent the averaged results of the sled testing.

Compartmentalized and lap belted seats include those models manufactured by BlueBird, Thomas Bus, and the C.E.White Co., both the standard height and high back model variations. The lap/shoulder belt data include the Bus Belt, C.E.White Co. and IMMI seats, while the lap/shoulder belt misuse tests were conducted only with the C.E.White Co. seats in early testing. The airbag lap belt restraints (AMSAFE) were installed on BlueBird's lap belted, reinforced seat design. Individual test results are available on NHTSA's Vehicle Crash Test Database (http://www-nrd.nhtsa.dot.gov/database/nrd-11/veh_db.html).

Figure 17 is a summary chart of the head injury criterion results, HIC_{15}, which has been normalized to the pass/fail criterion value of 700. A value of 1.0 on this chart represents a HIC_{15} of 700, or approximately a 30 percent risk of serious injury.

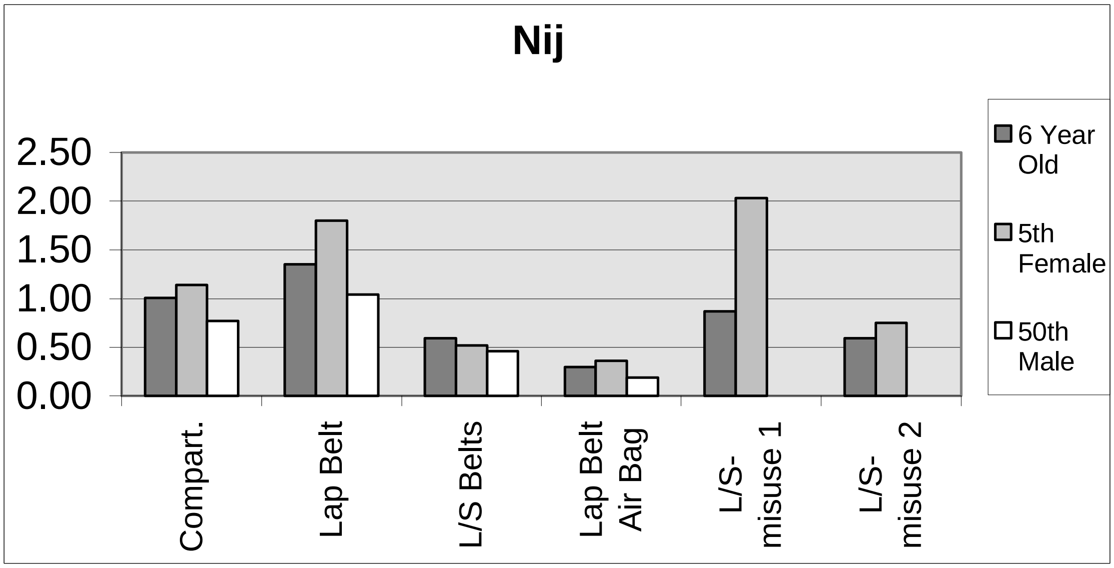
The unbelted, or compartmentalized, tests had similar HIC_{15} results to those of the lap belt restraint tests for all age/size groups. While the lap belt restraint changed the kinematics of the dummy's impact into the forward seat back, the overall velocity of the head impact was comparable and both seat designs utilize seat backs that meet the compartmentalized seat's force versus deflection requirements. The lap/shoulder belt restraint tests, which typically prevented or greatly reduced the head impact into the seat back, had HIC_{15} response levels lower than either the compartmentalized or lap belt restrained dummies. The limited testing with the inflatable airbag lap belt restraint resulted in the lowest overall responses for the 6-year-old and 50th percentile adult male dummy while the HIC_{15} response for the 5th percentile female dummy was comparable to that of the compartmentalized and lap belt restrained dummies. Film analysis of the tests suggests that when the head was fully cushioned by the airbag, the very low HIC_{15} values were observed. When the head partially impacted the seat back, somewhat higher HIC_{15} responses occurred. However, it should be noted that the HIC_{15} response for all of these tests were low and represent a low risk of serious injury to the occupant.

Figure 18 is a chart summarizing the neck injury (Nij) results. The FMVSS 208 pass/fail tolerance limit for this criterion is 1.0, which represents a 22 percent risk of serious neck injury. A value of 2.0 equates to a 67 percent risk of serious injury. Both the lap/shoulder belt restraint systems and the AMSAFE inflatable airbag lap belt system had lower Nij responses. The lap/shoulder belt restraints reduced or prevented head impact, thus the only loading on the neck was the inertial loading of the head. The inflatable airbag lap belt restraint cushioned the head impact while supporting the head, thus reducing the extension of the neck. The lap belt



- "L/S misuse 1" - shoulder belt routed behind the dummy's back
- "L/S misuse 2" - shoulder belt routed under the dummy's arm

Figure 17. Summary of Average HIC_{15} Values for Frontal Sled Tests.



- "L/S misuse 1" - shoulder belt routed behind the dummy's back
- "L/S misuse 2" - shoulder belt routed under the dummy's arm

Figure 18. Summary of Average N_{ij} Values for Frontal Sled Tests.

restraint tests showed a significant potential of risk for severe injury for some seat spacing/dummy stature conditions, while the “misuse 1” tests with the lap/shoulder belt restraints, which approximated a lap belt restraint system, showed potential for a high degree of risk for severe injury similar to that of the lap belt restraints.

Figure 19 is a summary chart of the average 3 ms Chest G results. The averaged data were normalized to the 60 g criterion limit. None of the tests conducted with any of the restraint systems showed significant risk of serious injury. The general kinematics, along with the closely spaced and padded seat backs, provided good protection for the unrestrained and lap belted occupants. The shoulder portion of the lap/shoulder belt restraints did potentially apply load to the chest, but the relatively low peak acceleration levels within the passenger compartment of the bus limited this loading. Results for the inflatable airbag lap belt restraint were similar to those for the lap/shoulder belt restraint, but appeared to be more occupant size dependent than some of the other restraint systems.

Effect of Seat Back Height - The most significant effect of increasing the seat back height, from the minimally required 508 cm (20 in) above the SRP, was the containment of the 50th percentile adult male dummy when tested in the compartmentalized configuration. There were several tests in which an unrestrained 50th percentile adult male dummy overrode a standard height seat back and struck a dummy positioned in the seat in front. High HIC_{15} values were observed in these tests in which this incidental contact occurred.

The seat back height, in general, did not appear to be a highly significant factor affecting the HIC_{15} and N_{ij} values observed for the 6-year-old and 5th percentile female dummies.

Effect of Seat Spacing - As stated previously, sled tests were conducted with the school bus seats positioned at three different spacing – 48 cm (19 in), 56 cm (22 in) and 61 cm (24 in). No consistent trends were observed for any dummy size in the limited number of tests with different seat spacing.

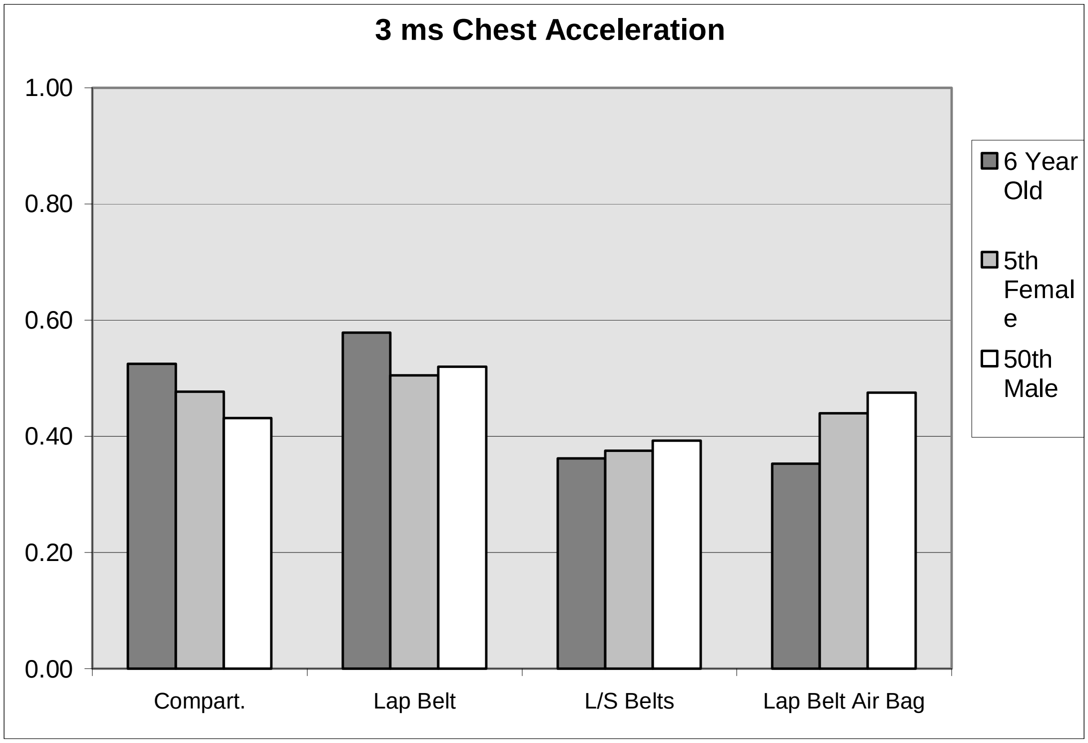


Figure 19. Summary of Average 3 ms Chest G Values for Frontal Sled Tests.

Concern about Abdominal Loading with Lap Belt Restraint Systems -When properly positioned, the lap belt system restrains an occupant by loading them across the hard pelvic structure. When used in conjunction with a shoulder belt, a portion of the load is also distributed across the upper torso. When a lap belt restraint is improperly positioned, due to improper fit or misuse, this load produced by the belt can be transmitted to the occupant through the soft abdomen, rather than across the hard structure of the pelvis. This has been shown to produce serious-to-fatal injuries in automotive crashes.

Current frontal crash test dummies are not designed to measure abdominal forces, and there are no criteria currently available to predict injury if such forces were determined. While some efforts were made to measure these loads in the first series of sled tests, the results were largely inconclusive. The data from these tests were reported in NHTSA's April 2002 Report to Congress, "School Bus Safety: Crashworthiness Research" [2] and are available on NHTSA's Vehicle Crash Test Database.

SIDE IMPACT RESEARCH

Research of the available crash data by NHTSA indicates that being impacted in the side by a heavy truck is, after front and rear impacts, the next most prevalent source of serious injury or fatality to school bus occupants. The agency conducted a side impact test in which a heavy truck (a cab-over tractor ballasted to 11,406 Kg) was towed into the side of a school bus at 72.4 km/h [1]. Despite the severity of this crash, the dummy responses indicated no significant threat of severe injury to those occupants located outside of the direct impact zone.

NHTSA is conducting ongoing research to quantify the magnitude of the injury problem to school bus occupants during a side impact, and to evaluate potential methods for mitigating these injuries. Crash data analysis is continuing to better define the conditions and locations of head impacts that produce injury to occupants in bus crashes. Also, the agency is contracting with Mercer University's Engineering Research Center (MERC), in a joint research effort to: (1) develop a finite element model of a typical school bus construction, and (2) study the effects on occupant protection of various levels and types of padding added to the bus sidewall and/or roof area.

The agency's Vehicle Research and Test Center (VRTC) has conducted a series of preliminary dynamic component tests to assess the threat of head injury when contacting various portions of the upper interior of the school bus. This includes the roof and areas surrounding the side windows and emergency exits. These tests used the free-motion head-form specified for use in FMVSS 201 to evaluate the potential for head injury and to identify potential injury mitigating structures currently present in some buses.

CONCLUSIONS

The following conclusions are based on the results from the Initial [1] and Phase II sled test series (discussed in this paper):

1) Compartmentalization
    a) Low head injury values were observed for all dummy sizes, except when override occurred (i.e., when the large male dummy overrode the seat in front of it).
    b) High back seats prevented this override phenomenon from occurring.
    c) Approximately half of the tests with the 6-year-old and 5th percentile female resulted in high N_{ij} values.

2) Lap Belt Restraint System
    a) Lap belt restraints effectively kept the dummies in their seats.
    b) HIC_{15} values were low for all dummy sizes.
    c) N_{ij} values were high for most of the dummies, and were generally higher than those from the compartmentalization tests.
    d) Neck injury potential was very sensitive to seat spacing and occupant size, with many tests producing N_{ij} values in excess of twice the criterion threshold.

3) Lap/Shoulder Belt Restraint System
    a) Lap/shoulder belt restraints effectively kept dummies in their seats.
    b) HIC_{15} values were low for all dummy sizes., and were significantly lower than compartmentalization and lap belt restraint results.
    c) When the restraints were properly worn, the N_{ij} values were below the criterion value for all size dummies.
    d) Restraint misuse – putting the shoulder belt behind the dummy's back or under the dummy's arm – can produce undesirable results.
    e) The stiffer seat back, required for anchoring the shoulder belt upper anchorage, could present a potential problem for the unbelted occupant(s) seated behind an occupant who

   is secured with the lap/shoulder belt restraint.
   f) Stiffer seat back design issues may be addressed by proper design and/or padding of the seat.

4) Inflatable Airbag Lap Belt Restraint System
   a) The airbag lap belt restraint appeared to cushion and/or prevent head impacts into the seatback in front of the occupant.
   b) The restraint system appeared to support the occupant's head, reducing loading on the neck.
   c) HIC_{15}, N_{ij} and 3 ms chest g values were similar in magnitude to those observed for lap/shoulder belt restraints.

REFERENCES

1. Elias, J.C.; Sullivan, L.K. and McCray, L.B., "Large School Bus Safety Restraint Evaluation", 17th International Technical Conference on the Enhanced Safety of Vehicles, Amsterdam, June 4-7, 2001.

2. United States Congressional Report, "School Bus Safety: Crashworthiness Research", April, 2002. Available at http://www-nrd.nhtsa.dot.gov/departments/nrd-11/SchoolBus.html