

## **CHILD SAFETY RESEARCH IN SCHOOL BUSES**

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### **ABSTRACT**

School bus transportation is one of the safest forms of transportation in the United States. Every day, our nation's 440,000 public school buses transport more than 23.5 million children to and from school and school-related activities.

The safety record is impressive: American students are nearly eight times safer riding in a school bus than with their own parents and guardians in cars. The fatality rate for school buses is only 0.2 fatalities per 100 million vehicle miles traveled (VMT) compared to 1.5 fatalities per 100 million VMT for cars.[1]

School buses have annually averaged about 26,000 crashes resulting in 10 deaths – 25 percent were drivers; 75 percent were passengers. Frontal crashes account for about two passenger deaths each year.

This paper describes past, present and near-term school bus research efforts.

### **INTRODUCTION**

The safety record for school bus transportation exceeds that of all other modes of travel. Students are nearly eight times safer riding in a school bus than in cars. Each school day, 440,000 public school buses transport 23.5 million children. The fatality and injury rates associated with school buses are consistent from year to year. On average, about seven passengers die in school bus crashes each year. In 2003, five passengers and six drivers died in school transportation vehicles (this includes school buses and other vehicles used as school buses), and 21 pedestrians were killed when struck by a school bus. NHTSA has several standards relating to school bus safety. NHTSA's requirements for compartmentalization on large and small school buses, plus safety belts on small buses contribute to the safe environment.

As a result of the passage of the National Traffic and Motor Vehicle Safety Act of 1966 and the School Bus Safety Amendments of 1974, NHTSA currently has 35 Federal Motor Vehicle Safety Standards (FMVSS) that apply to school buses. The 1974 amendments directed NHTSA to establish or upgrade school bus safety standards in eight areas: emergency exits, interior occupant protection, floor strength, seating systems, crashworthiness of the body and frame, vehicle operating systems, windshields and windows, and fuel systems.

### **BACKGROUND**

During the rulemaking process in the early 1970's, when the school bus safety standards were being established, NHTSA looked carefully at available injury and fatality data, existing research, and public comments submitted to the agency to determine what system of occupant protection should be required in school buses. Research conducted at UCLA in 1967 and 1972 evaluated existing seats on school buses. That research showed that school bus seating systems at that time did not provide adequate protection for the school bus passengers. Those findings led NHTSA to issue a contract to AMF Corporation to design new, protective school bus seating systems that provided uniform levels of protection to seated occupants ranging in size from a six-year old (21 kg (46 pounds) and 1,219 mm (48 inches) in height) to a 50th percentile male (75 kg (165 pounds) and 1,778 mm (70 inches) in height).[2]

Recognizing that school bus vehicles i) are generally heavier than their impacting partners, ii) impart lower crash forces on their occupants, and iii) distribute crash forces differently than do passenger cars and light trucks in crashes, it was determined that the best way to provide crash protection to children on large school buses was to use a concept called "compartmentalization." This concept provides a protective envelope consisting of strong, closely spaced seats that have energy-absorbing seat backs. These requirements are found in FMVSS No.

222, School bus passenger seating and crash protection, which became effective for newly manufactured school buses on or after April 1, 1977. This standard has not changed significantly since its inception.

### **Current School Bus Passenger Crash Protection**

Even though compartmentalization has proven to be an excellent concept for injury mitigation, NHTSA initiated an extensive research program to develop the next generation occupant protection system(s). The protective abilities of today's school buses have been reaffirmed by two years of research. No matter how safe our children are on school buses, it is vitally important to constantly reassess existing safety measures.[3] During this timeframe the National Transportation Safety Board (NTSB) had begun special investigations on school bus crashes.

### **National Transportation Safety Board Recommendations**

The National Transportation Safety Board (NTSB) initiated a special investigation to determine whether additional measures should be taken to better protect bus occupants. It examined school bus and motorcoach crashworthiness issues through the analysis of 6 school bus and 40 bus crashes and through information gathered at the Safety Board's August 12, 1998 public hearing. The special investigations addressed, in part, the crucial safety issues regarding the effectiveness of current school bus occupant protection systems. As a result of the investigations, the NTSB issued three safety recommendations pertaining to passenger crash protection in school buses.[4]

Recommendation H-94-010 was initiated to require NHTSA to evaluate occupant restraint systems, including those presently required for small school buses. The recommendation was made as a result of a crash between a small school bus and a tractor-trailer dump truck. The crash resulted in four passenger fatalities, all of whom were ejected from the school bus. In the investigation the Safety Board noted that the children were not instructed to wear the required lap belts due to the potential risk of injuries from use of lap belts in frontal impacts.

Safety Recommendations H-99-45 & H-99-46 were initiated to encourage NHTSA to develop and implement performance standards for school bus occupant protection systems that take into account frontal impact collisions, side impact collisions, rear impact collisions, and rollovers. These

recommendations resulted from the 1999 study on bus crashworthiness issues. NTSB evaluated six selected school bus crashes for this study. Based on that analysis, the Safety Board came to the conclusion that the current "compartmentalization" is incomplete in that it does not adequately provide protection in all crash scenarios.[5]

Safety Recommendation H-00-28 was initiated to encourage NHTSA to modify the Federal Motor Vehicle Safety Standards to prohibit protruding door handles or latching mechanisms on emergency doors. This recommendation resulted from a crash in October 1999 with a school bus/dump truck/utility trailer near Central Bridge, NY. NTSB concluded that, although the side emergency exit door met safety regulations, it presented a hazard for passengers because portions of door release mechanism protruded into the passenger compartment potentially injuring a person on the latch assembly. This seems to imply that it is unsafe to sit next to a side emergency exit door.

Thus far, the agency's school bus research efforts have focused on addressing these and other Safety Board recommendations.

### **NHTSA's School Bus Research**

As previously noted, no matter how safe our children are on school buses, it is vitally important to regularly reassess existing safety measures. Therefore, Congress requested that the Department of Transportation investigate potential approaches that could further enhance safety protection offered on our nation's school buses. An April 2002 report to Congress documents the program findings.[6]

The agency began a research program to investigate potential approaches that could further enhance safety on school buses. Phase I of the research program was to identify safety problems. The NHTSA reviewed several sources of information in an effort to define the effectiveness of the existing FMVSS requirements applicable to school buses. Data from the agency's FARS (Fatality Analysis Reporting System), NASS (National Automotive Sampling System)-GES (General Estimates System), and SCI (Special Crash Investigations), along with state and local officials' crash information and data from the NTSB were analyzed.

The problem determination showed that (1) most fatalities occurred for occupants of large school buses, and (2) the most significant factors in fatal, two-vehicle crashes are that they occur on roadways where the posted speed limit is 88-97 kph (55-60

mph) and involve heavy trucks (83% frontal impacts and 15% side impacts). Based on the analytical results from Phase I, two full-scale crash tests were defined to be representative of the real-world environment of large school bus crashes.[7]

### **Frontal Impact Research**

The agency conducted a frontal crash test of a large conventional style school bus (Class C) into a rigid barrier at 48 kph (30 mph) to evaluate the protection afforded by compartmentalization. Instrumented dummies of various sizes were used ranging from the 50th percentile male representing an adult or a large size teenager to the 6-year-old child. A small frame 5th percentile female adult (representing a large 12-year-old child) was also used in that test. In addition to measuring the dummy injury measures in the crash test, one other objective was to determine the crash pulse experienced in such school bus crashes so that similar tests could be carried out in a simulated sled environment.

The full-scale crash tests showed that the head and chest injury measures for all dummies were far below the accepted injury threshold values in frontal crashes. However, the FMVSS No. 208 neck injury criteria could not be met by neither the 6-year-old child dummies nor the 5<sup>th</sup> percentile female dummies in the frontal crash test.

Phase II of the program was the development of the frontal sled test pulse and evaluation of various restraint configurations in frontal crashes. A series of 25 sled tests was conducted using two sled bucks with various size dummies for evaluation of seats designed to comply with existing compartmentalization requirements as well as to evaluate the protection offered by lap belts and lap/shoulder belt systems in frontal crashes. Full details of these efforts are provided in ESV Papers No. 345[8] and Paper No. 313[9].

In response to the NHTSA research effort, the agency has pinpointed other improvements that could be made to improve the safety of school buses. The agency is considering the following changes to existing federal safety regulations: 1) increased seat back height to reduce the potential for passenger override in the event of a crash; 2) require lap/shoulder belt restraints in buses under 4536 kg (10,000 pounds); and 3) require standardized test procedures for voluntarily installed lap/shoulder belts .[10]

### **Side Impact Research**

A full-scale side impact test was conducted by towing an 11,406 kg (25,265 lb) cab-over heavy

truck, at 72 kph (45 mph) and 90°, into the side of a transit style school bus (Class D).



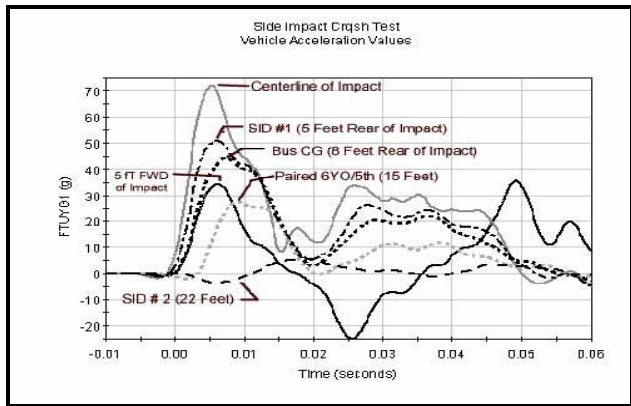
**Figure 1 Pre-Test Photograph of Side Impact School Bus Crash Configuration**

Pre- and post-test configurations are shown in Figures 1 and 2, respectively. Two 50th percentile male side impact dummies (SIDs), along with the Hybrid III 5th percentile female and 6-year-old frontal dummies, were positioned in selected seating locations in the side impact test. One Hybrid II 50<sup>th</sup> percentile male dummy was located at the direct point of impact to determine “survivability” within the impact zone.



**Figure 2 Post-Test Photograph of Side Impact Crash Test**

In the side impact test the dummy injury measures for the head, and the chest g's for the frontal dummies and the thoracic trauma index for the side impact dummy were far below the established threshold levels for those dummies not directly in the impact zone. The crash pulse varied depending on the relative location with respect to the point of impact. Accelerometers were positioned along the length of the school bus. The acceleration time histories are shown in Figure 3. No single pulse is fully representative of the range of vehicle responses observed in the side impact crash test. Acceleration levels dropped significantly away from the point of impact. [11]



**Figure 3. Side Impact School Bus Acceleration at Various Locations in the Bus**

### Exploratory Side Impact Research

As previously noted, no single pulse is fully representative of the range of vehicle responses observed in the side impact crash test. The agency's Vehicle Research and Test Center (VRTC) conducted a small number of free-motion head-form impactor tests to determine the feasibility of reducing head injury and also to determine the feasibility of test methodology to assess side impact protection.

The exploratory research effort focused on impacting hard, interior contact surfaces. The areas of impact included: the top of the window frame, wheelchair belt attachment/mount, center of roof header, upper seam on roof header, window cross bar, side of window frame, upper roof rib, upper window frame, emergency exit hinge and above the emergency exit hinge. These surfaces were impacted at a speed ranging from 22 to 28 kph (15 – 17 mph). The 24 kph (15 mph) impactor target speed is the current test speed used in the FMVSS No. 201, *Occupant Protection in Interior Impact*, for occupant interior protection. It was believed that impactor test speeds similar to those used in FMVSS No. 201 was a reasonable starting point until further side impact research could be conducted. The head injury criterion (HIC) values were evaluated and some exceeded the injury assessment reference values. It was observed that the impact areas that were covered with raised sheet metal yielded lower HIC values. Raised sheet metal was applied to some locations in which high HIC values occurred. This effort demonstrated that high HIC responses can be reduced with the proper countermeasure application. The effect this would have on reducing real-world injuries cannot be quantified until the data analysis described in the next section of this paper is completed.

## **RESEARCH APPROACH**

Most of the earlier school bus research efforts focused on frontal crash protection. The current focus of the school bus research program is on side impact protection.

A 9-step approach has been undertaken for this school bus side impact research program. The approach includes the following steps:

1. Select and define a crash problem
2. Set countermeasure functionality
3. Survey technology for functions
4. Create countermeasure concepts
5. Estimate preliminary costs and benefits
6. Select the most promising concept(s)
7. Develop and conduct objective tests
8. Refine costs and benefits
9. Agency decision on next steps

Step 1 of the approach focuses on defining the safety problem. Earlier efforts that were undertaken identified that multi-vehicle impacts with trucks were the most injurious types of side impact school bus crashes. These crashes typically occurred on roadways with posted speed limits of greater than 72 kph (45 mph). In order to best focus agency resources, a preliminary estimation of costs and benefits must be determined (step 5). Steps 2 through 4 must be conducted at minimum costs to help identify the most feasible approach to be taken. These engineering evaluations are based on sparse data to direct a greater investment in countermeasure test development and benefits analyses. Once the preliminary estimation of benefits is determined, steps 6 and 7 are conducted. Based on these results, the costs and benefits are refined in step 8. Step 9 is an agency decision-making step. In this phase of the process, the research results, along with cost and benefits, are then assessed by the agency to determine the next action to be undertaken. While research efforts are conducted within the framework of steps 1 – 8, Agency involvement occurs throughout the entire process.

### **Problem Definition Underway**

#### Database Interrogation and Synthesis

A database interrogation and synthesis is being conducted to provide the status of injury and sources of injuries to children in side impact school bus

crashes. The framework of this effort encompasses Steps 1, 5 and 8 of the research approach.

The intent of this phase is to expand and update earlier approaches that attempt to define total frequency of injuries to children.[12] The analysis includes side impact crashes of full-size school buses. To the extent possible, segmentation of the data will include occupant age, occupant location (near or far side relative to impact), occupant restraint system used (e.g. compartmentalization vs. other restraint systems), crash orientation (right side vs. left side), injury location (head, thorax, etc.), and injury severity (AIS). Data on both absolute occurrences (total frequency) and rates relative to exposure (i.e., normalized by relevant vehicle miles traveled) will be pursued. An attempt will also be made to assess whether multiple impacts (including rollover) can be correlated with more severe injuries.

Fortunately, school bus crashes that result in fatalities are rare. For this reason, 101 school bus crashes since 1980 with associated fatalities can be studied on a case-by-case basis. Of these, 40 are side impact crashes. The cases have been extracted from FARS. Further information on each case should be available through the police accident report. Although the statistical significance of relative trends may be limited, the ability to ascertain details of these rare events should be valuable.

### **Next Steps**

Once the police reports have been reviewed, a more reasonable assessment of potential countermeasures can be made. This will serve as a foundation on which steps 1 – 8 of the process can be pursued.

### **CONCLUSIONS**

This paper sought to describe the status of child safety research related to school buses. It has shown that school buses are an especially safe mode of transportation. Nonetheless, given their importance to posterity, further research is warranted. The authors will continue their work to identify and exploit opportunities for increased safety.

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