REPORT TO CONGRESS

School Bus Safety: Crashworthiness Research

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Executive Summary

School bus transportation is one of the safest forms of transportation in the United States. Every year, our nation's 450,000 public school buses travel more than 4.3 billion miles to transport 23.5 million children to and from school and school-related activities.

The 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.

This impressive safety record is a result of the Department of Transportation's requirements for compartmentalization on large school buses, and lap belts plus compartmentalization on small school buses. Moreover, the protective abilities of today's school buses have been reaffirmed by two years of research.

Yet, no matter how safe our children are on school buses, it is vitally important to constantly reassess existing safety measures. Therefore, Congress requested that DOT investigate the safety value of installing safety belts on our nation's school buses.

An analysis of test data by the National Highway Traffic Safety Administration (NHTSA) has concluded that lap belts appear to have little, if any, benefit in reducing serious-to-fatal injuries in severe frontal crashes. On the contrary, lap belts could increase the incidence of serious neck injuries and possibly abdominal injury among young passengers in severe frontal crashes. Any increased risks associated with the use of lap belts in small school buses are more than offset by preventing ejections. The use of the combination lap/shoulder belts could provide some benefit, unless misused. Lap/shoulder belts can be misused and NHTSA's testing showed that serious neck injury and perhaps abdominal injury could result when lap/shoulder belts are misused.

Other considerations, such as increased capital costs, reduced seating capacities, and other unintended consequences associated with lap/shoulder belts could result in more children seeking alternative means of traveling to and from school. Given that school buses are the safest way to and from school, even the smallest reduction in the number of bus riders could result in more children being killed or injured when using alternative forms of transportation.

Over the past 11 years, 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.

Meanwhile, NHTSA is continuing its research program, focusing on side impact protection, working with university-based researchers to further study school bus crashworthiness.

1.0 Research Plan

School buses are one of the safest forms of transportation in the United States. Every year, approximately 450,000 public school buses travel an estimated 4.3 billion miles to transport 23.5 million children to and from school and school-related activities. The school bus occupant fatality rate of 0.2 fatalities per 100 million vehicle miles traveled (VMT) is much lower than the overall rate for motor vehicles of 1.5 per 100 million VMT.[1] An average of 10 occupants die each year in school buses, including school, church, and civic association use.

1.1 Research Funding/Mandate

In Fiscal Year 1998, Congress appropriated $700,000 to evaluate alternative safety restraint bar devices on school buses. NHTSA received approval from both the House and Senate Appropriations Committees to use this money to evaluate other occupant restraint devices, including lap belts, in school buses. On June 9, 1998, President Clinton signed the landmark Transportation Equity Act for the 21st Century (TEA-21). Sections 2007 (b), (c), and (d) of TEA-21 directs NHTSA to “conduct a study to assess occupant safety on school buses.” Further this section directs NHTSA to “examine available information about occupant safety and analyze options for improving occupant safety.” NHTSA was directed to spend up to $200,000 on school bus occupant safety research. Other provisions include conducting a study concerning the safety of all transportation modes used in school transportation, i.e., school buses, transit buses and other passenger vehicles.

On June 25, 1998, Congressman James A. Traficant, Jr., wrote the Secretary of Transportation urging the department to consider the following when reviewing school bus occupant safety:

1. Impact on school districts of requiring school buses to have occupant restraint systems,
2. Design and operational considerations that would arise if occupant restraints on school buses are mandated, i.e., school bus seating capacity and restraint systems design that realistically deal with different sized occupants, and
3. All existing technologies.

In August 1998, NHTSA published a report titled, “School Bus Safety: Safe Passage for America’s Children.” The report outlines NHTSA’s current and future actions on school bus safety. Much of that planned work is documented in this report.

On April 23, 2001, NHTSA submitted a letter report documenting the current status of its school bus crashworthiness research program to the then Acting Deputy Assistant Secretary, DOT, at the request of Senator Kay Bailey-Hutchison. This letter report provided research findings in the following areas: statistical crash data, results of a detailed literature study of school bus occupant restraint systems, preliminary findings from analysis of 31 crash investigations, an overview of two full scale school bus tests – one frontal and one side, a review of NHTSA’s research

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[1] If one considered the average number of passengers on school buses versus passenger cars, there would be even a larger difference in the fatality rates per passenger mile.

program on occupant restraint, research findings, and preliminary recommendations for school bus occupant protection.

1.2 Research Program Objectives

Even though compartmentalization has proven to be an excellent form of occupant protection, the agency has initiated a comprehensive research program to develop the next generation of school bus occupant protection. The objective of NHTSA's Research Plan was to:

1. Determine the real-world effectiveness of current Federal requirements for school bus occupant crash protection,
2. Evaluate alternative occupant crash protection systems in controlled laboratory tests that represent the types of real-world school bus crashes, and
3. Provide research findings to support agency activities related to the next generation of occupant protection requirements for school buses.

The following guidelines were use to select systems for inclusion in this research program:

1. Reduce the total number of injuries or fatalities associated with school bus crashes,
2. Protect the whole range of school bus occupants,
3. Feasibility,
4. Reasonable cost,
5. Maintain occupant capacity of school buses, and
6. Maintain emergency evacuation.

1.3 School Bus Occupant Protection Requirements

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.

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 great weaknesses in those seating systems. 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 (46 pounds and 48 inches in height) to a 50th percentile male (165 pounds and 70 inches in height).

Recognizing that school bus vehicles are generally heavier than their impacting partners, impart lower crash forces on their occupants, and 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 method provides a protective envelope consisting of strong, closely spaced seats that have energy-absorbing seat backs. This requirement became effective for newly manufactured school buses on or after April 1, 1977. Compartmentalization along with the enhanced safety standards such as joint integrity of the bus body panels and stringent fuel system integrity requirements make school buses the safest vehicles on the road.

2.0 Vehicle Data

Every year, approximately 450,000 public school buses travel about 4.3 billion miles to transport 23.5 million children to and from school and school-related activities.

During the past few years, school bus sales have increased. According to School Transportation News[2], 47,670 school buses were manufactured between September 1, 1999 and August 31, 2000. Table 1 presents data on different types of school buses manufactured between 1995 and 2000.

Table 1. Annual School Buses Production

School year	Type A	Type B	Type C	Type D	Total
1999-2000	10,181	250	25,898	11,341	47,670
1998-1999	10,475	252	24,610	10,257	45,694
1997-1998	8,185	471	22,260	10,164	41,080
1996-1997	5,334	400	24,912	9,259	37,181
1995-1996	6,585	393	22,308	9,311	38,597

Type A, B, C, and D are industry terms[3] used to distinguish the different types of school buses. NHTSA basically has two types of school buses – those greater than 10,000 pounds Gross Vehicle Weight Rating (GVWR) and those with a GVWR less than or equal to 10,000 pounds. A Type A school bus is a conversion or bus constructed utilizing a cutaway front-section vehicle with a left side driver's door. This definition includes two classifications – Type A1, with a GVWR of 10,000 pounds or less, Type A2, with a GVWR greater than 10,000 pounds. A Type B school bus is constructed utilizing a stripped chassis. The entrance door is behind the front wheels. This definition includes two classifications – Type B1, with a GVWR of 10,000 pounds or less, Type B2, with a GVWR greater than 10,000 pounds. A Type C school bus is constructed utilizing a chassis with a hood and front fender assembly. The entrance door is ahead of the front wheels. A Type D school bus is constructed utilizing a stripped chassis. The entrance door is ahead of the front wheels. Type D buses are also known as "transit style" or "forward control" buses.

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[2] *The 2001 School Transportation News Buyer's Guide*, School Transportation News, October 2000

[3] National School Transportation Specifications and Procedures, May 2000

3.0 Crash Data Statistics

On average 10 occupants die in school buses each year – 25 percent drivers and 75 percent passengers.

The school bus occupant fatality rate is 0.2 fatalities per 100 million vehicle miles traveled. This is about eight times lower than the 1.5 per 100 million VMT for all motor vehicles. On average, 10 occupants die each year in school bus crashes.

3.1 Statistical Methods

An analysis was conducted of the data related to fatalities and injuries in school bus crashes from NHTSA's Fatality Analysis Reporting System (FARS) and National Automotive Sampling System (NASS) General Estimates System (GES) databases. FARS is a census of fatal crashes within the 50 States, the District of Columbia, and Puerto Rico. NASS-GES is a probability-based sample of police-reported crashes, gathered from 60 locations across the country, from which national estimates of injury producing and property-damage-only crashes are derived. Analysis also was conducted on crash and injury statistics based on data from the NASS-GES.

NHTSA reports school transportation-related fatalities and injuries yearly in its annual *(year) Traffic Safety Facts* book and in a special annual publication titled *Traffic Safety Facts (year) – School Buses*. These data account for all school transportation-related deaths and injuries involved in transporting students to and from school and school related activities. From time to time, non-school buses are used for this purpose and when these vehicles are involved in a fatal or injury producing crash they are included in the count/estimate for those reports. The analyses presented in this report have been restricted to include school buses, regardless of use, and exclude school-related, non-school bus crashes.

3.1.1 School Buses Crash Analysis

The following data apply directly to school buses, and include school-related use as well as non-school-related activities, such as churches and civic associations. These analyses are limited to 1977 through 2001 model year vehicles, normally referred to as the post-standard vehicles because they included many enhancements required by several FMVSS standards promulgated in the early 1970s to improve the safety of school buses. During this time, there were 112 fatalities – 93 fatalities in school-related school buses and 19 fatalities in non-school-related school buses.

Table 2 presents the number of occupant and driver fatalities by year, from 1990 through 2000. On average, just over 10 persons are killed each year as occupants in school buses. Seventy-five percent of the fatalities are passengers. About 83 percent of these fatalities occur during school-related activities, while the remaining deaths are non-school-related. Also, during this same time, there were 6 fatalities in pre-1977 school buses.

Table 3 presents the estimated number of crashes and injuries for drivers and passengers in school buses, from NASS-GES. On average, over the past 11 years, school buses have been involved in over 26,000 crashes, resulting in slightly less than 1,000 incapacitating injuries and slightly more than 7,000 non-incapacitating evident injuries and possible injuries to passengers. Drivers sustain considerably fewer injuries.

Table 2. School Bus Occupant Fatalities

Year	School Transportation-Related						All Uses		
	No			Yes					
	Driver	Pass	Total	Driver	Pass	Total	Driver	Pass	Total
1990	1	1	2	4	6	10	5	7	12
1991	0	0	0	1	9	10	1	9	10
1992	0	0	0	1	4	5	1	4	5
1993	0	0	0	1	9	10	1	9	10
1994	0	2	2	0	0	0	0	2	2
1995	0	5	5	0	12	12	0	17	17
1996	2	7	9	2	6	8	4	13	17
1997	0	0	0	3	5	8	3	5	8
1998	0	0	0	3	3	6	3	3	6
1999	1	0	1	5	3	8	6	3	9
2000	0	0	0	5	11	16	5	11	16
Total	**4**	**15**	**19**	**25**	**68**	**93**	**29**	**83**	**112**
Average/Year (Total/11)	**0.4**	**1.4**	**1.7**	**2.3**	**6.2**	**8.5**	**2.6**	**7.5**	**10.2**

Full description: Occupant Fatalities in School Buses; (Model Year 1977-2001); By Person Type; Source: FARS 1990-2000

3.1.2 Passenger Deaths in School Buses

NHTSA reviewed all the crashes where passengers were killed in 1977 through 2001 model year school buses, including those in school-related and non-school-related use for 1990 through 2000. There were 55 such crashes during the 11-year period, in which 83 passengers were killed. During this period, the annual average is 5 fatal-passenger crashes and 7.5 passenger fatalities. The FARS codes school buses in two categories, van-based school buses and school buses (which will be identified as full-sized in the following analysis to avoid confusion). Table 4 presents the number of occupant fatalities by these two categories for school buses.

A review of these data indicates about 20 percent of the passenger fatalities are occurring in van-based school buses. Typically, these vehicles are equipped with seat belt systems. Table 5 further distributes these passenger fatalities by most harmful event.

Table 3. School Bus Crashes and Injuries.

Year	Crashes	Injured Passengers		Injured Drivers	
		A Injuries	B & C Injuries	A Injuries	B & C Injuries
1990	25,424	821	16,614	14	1,979
1991	22,866	375	5,460	4	1,010
1992	21,436	5,881	4,175	270	1,320
1993	27,042	825	4,387	152	1,480
1994	23,802	126	7,163	135	1,145
1995	28,805	78	6,813	12	2,034
1996	26,699	132	6,058	105	1,137
1997	28,099	824	8,691	199	1,572
1998	27,371	675	3,862	52	1,569
1999	29,756	132	8,300	9	1,345
2000	28,065	359	7,230	474	1,039
Total	**289,365**	**10,228**	**78,753**	**1,426**	**15,630**
Average/Year (Total/11)	**26,306**	**930**	**7,159**	**130**	**1,421**

Notes:

1. There are a few unknown severity injuries. These were not included in this analysis
2. The NASS-GES system has a Standard Error (SE) associated with each observation. For crashes, a measurement of 30,000 crashes has a SE of 3,200. For injuries, estimates of 1,000, 5,000, and 10,000 have SEs of 400, 1,000, and 1,500, respectively. Lower estimates of injuries have high SEs.
3. A = Incapacitating Injury; B = Non-incapacitating Evident Injury & C = Possible Injury

Full description: School Bus Crashes and Injuries by Occupant Type, Source: NASS-GES 1990–2000

Table 4. School Bus Passenger Fatalities.

Body Type	Fatalities	Fatalities per Year	Percent
Full Sized	66	6.0	80 %
Van Based	17	1.5	20 %
Total	**83**	**7.5**	**100 %**

Full description: Passenger Fatalities in a School Buses by Body Type, Source: FARS 1990-2000

Table 5. School Bus Passenger Fatalities by Most Harmful Event.

Event	School Bus Type					
	Full-Sized		Van-Based		All	
	Total	Per Year	Total	Per Year	Total	Per Year
Vehicle in Transport	27	2.4	5	0.5	32	2.9
Overturn	1	0.1	12	1.1	13	1.2
Rail Train	13	1.2	0	0	13	1.2
Fell from Vehicle	10	0.9	0	0	10	0.9
Tree	6	0.5	0	0	6	0.5
Utility Pole	6	0.5	0	0	6	0.5
Embankment Unknown	1	0.1	0	0	1	0.1
Non collision	1	0.1	0	0	1	0.1
Pole	1	0.1	0	0	1	0.1
Total	**66**		**17**		**83**	
Average/Year (Total/11)	**6.0**		**1.5**		**7.5**	

Full description: Passenger Fatalities in a School Bus; (Model Year 1977-2001) by Body Type and Most Harmful Event; Source: FARS 1990-2000

During the past 11 years, van-based school bus vehicles have accounted for most of the passenger fatalities from vehicle overturn. Besides overturn, during the past 11 years, there have not been any passenger fatalities in single-vehicle crashes of van-based school buses. Van-based school buses accounted for about 15 percent of the passenger fatalities associated with multi-vehicle crashes.

Table 6 presents the number of passenger fatalities in school buses by body type and principal impact point. For all school bus crashes which result in a passenger fatality, frontal and side crashes produce the most fatalities, followed by non-collision (typically rollover) and rear crashes. For full-sized school buses the distribution is similar, but van-based vehicles have a different distribution, being void of frontal crashes that produce passenger fatalities. On average, over the past 11 years, 2 passengers have been killed per year in school buses in frontal crashes. While properly worn seat belt systems have the potential for reducing fatalities (and injuries) related with passenger ejections, there has only been one fatality over the past 11 years in full-sized school buses associated with overturn as the most harmful event. For full-sized buses, where lap belts have not been installed routinely, most of the benefit of installing seat belt systems (beyond increasing the usage rates of belts) will come from reductions in frontal-related fatalities (and injuries).

Table 6. School Bus Passenger Fatalities by Principal Impact Point.

Location	School Bus Vehicle Type					
	Full-Sized		**Van-Based**		**All**	
	Total	**Per Year**	**Total**	**Per Year**	**Total**	**Per Year**
Front	22	2.0	0	0	22	2.0
Side	17	1.5	5	0.5	22	2.0
Non collision	11	1.0	5	0.5	16	1.5
Rear	14	1.3	0	0	14	1.3
Unknown	0	0	6	0.5	6	0.5
Top/Undercarriage	2	0.2	1	0.1	3	0.3
Total	**66**		**17**		**83**	
Average/Year (Total/11)	**6.0**		**1.5**		**7.5**	

Full description: Passenger Fatalities in a School Bus; (Model Year 1977-2001) by Body Type and Principal Impact Point; Source: FARS 1990-2000

Table 7 presents the estimate of the number of passengers with incapacitating injuries (A-type) from NASS-GES data for school buses, distributed by location of impact on the bus.
An incapacitating injury[4] (A) is any injury, other than a fatal injury, which prevents the injured person from walking, driving, or normally continuing the activities the person was capable of performing before the injury occurred. Included injuries are: severe lacerations, broken or distorted limbs, skull or chest injuries, unconsciousness at or when taken from the crash scene, unable to leave the crash scene without assistance, complaint of pain, and others. Excluded are: momentary unconsciousness, and others.

These data indicate that the majority of the incapacitating injuries occur in frontal crashes. The average annual number of persons receiving incapacitating injuries (A-type) in frontal crashes over the past 11 years has been 660. There has been a wide variation in the number of injured persons in frontal crashes, with the estimate ranging from 0 for years 1993 through 1996 to nearly 6,000 in 1992.

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[4] ANSI D16.1 - 1996 Manual On Classification of Motor Vehicle Traffic Accidents

Table 7. School Bus Passenger Injuries.

Year	Front	Right-side	Left-side	Back	Under-carriage	No Damage	Total
1990	373	0	448	0	0	0	821
1991	10	146	99	4	0	116	375
1992	5,793	20	0	30	0	37	5,880
1993	0	517	288	0	0	20	825
1994	0	54	0	0	0	73	127
1995	0	0	54	0	5	18	77
1996	0	0	94	38	0	0	132
1997	147	0	0	677	0	0	824
1998	675	0	0	0	0	0	675
1999	19	0	0	113	0	0	132
2000	239	0	98	0	0	22	359
Total	**7,256**	**737**	**1,081**	**862**	**5**	**286**	**10,227**
Distribution	**71%**	**7%**	**11%**	**8%**	**0%**	**3%**	**100%**
Average/Year (Total/11)	**660**	**67**	**98**	**78**	**0**	**26**	**930**

Notes:

1. There are a few unknown severity injuries. These were not included in this analysis
2. The NASS-GES system has a Standard Error (SE) associated with each observation. For crashes, a measurement of 30,000 crashes has a SE of 3,300. For injuries, estimates of 1,000, 5,000, and 10,000 have SEs of 400, 1,000, and 1,500, respectively. Smaller estimates have high SEs.

Full description: Passengers of a School Bus; (Model Year 1977-2001) with Incapacitating Injuries (A-type); by Impact Location; Source: NASS-GES 1990-2000

3.2 School Bus Crash Investigations

In support of the school bus occupant restraint research program, NHTSA analyzed 31 school bus crashes that involved 35 school buses. These investigations were conducted by NHTSA's National Center for Statistics and Analysis (NCSA) Special Crash Investigation (SCI) Team and the National Transportation Safety Board (NTSB). Since these cases were selected without regard to national sampling procedures, no statistical inference can be made from this summary. However, these data do provide a general overview of crash outcomes in school bus crashes. Also, as mentioned earlier, these are NHTSA's only analyses based on direct observations of actual school bus crashes, since all statistical analyses are based on statistical crash data collected from police accident reports. Cases were not selected for investigations on injury outcome, but the cases investigated do include crashes where passenger fatalities or serious injuries occurred, as well as non-injury producing crashes. The following subsections summarize the observations were made based on this analysis.

3.2.1 Size of School Buses in Crashes

Thirty-five school buses were involved in the 31 school bus crashes investigated. Of the 35 school buses involved, 33 were large capacity buses (GVWR > 10,000 pounds) and two were small buses (GVWR ≤ 10,000 pounds).

3.2.2 Belt Use in School Bus Crashes

Seat belt systems were available on four of the large buses and the two small buses. There were insufficient data to make any determinations as to the effect of belt system use on preventing or minimizing injuries to the passengers.

3.2.3 School Bus Crash Type and Partner Vehicle

Two of the school bus crashes were single vehicle collisions. Twenty-nine of the school bus crashes involved one or more vehicles. In these multi-vehicle crashes, heavy trucks were involved more than any other type vehicle. Table 8 presents a listing of the various sizes of impacting vehicles. These data show that larger vehicles make up the majority of the partner vehicles, and about 70 percent of the vehicles involved are school bus size or larger.

Table 8. Impacting Vehicle

Type *	Frequency
Large Truck	13
Medium Truck	3
LTV	3
Car	5
School Bus	3
Train	2

* Large truck – GVWR > 26,000 pounds;
Med truck – GVWR 10,000 to 26,000 pounds

3.2.4 Direction of Impact for School Bus Crashes

An analysis of the principal direction of force in these crashes indicates a distribution somewhat like the national estimate, except frontal crashes appear to be underrepresented. Table 9 provides these data.

Table 9. Impact Location on Bus

Location	Number of Crashes by Location
Front	9
Left Side	10
Right Side	3
Rear	9

3.2.5 Occupancy and Injuries in School Bus Crashes

Occupancy of the school bus ranges from no passengers to over 50 passengers. The average for the buses in this analysis was about 17 passengers. Of the over 550 passengers in these vehicles, nearly 300 reported some level of injury, although the majority were minor in nature. Based on analyst review, there were about 30 moderate and about 30 serious to fatal injuries in these crashes. Further analyses indicate these approximately 60 more severe injuries were caused during left side impacts followed by frontal crashes. Although rear impacts were significant in frequency, they produced relatively few injuries.

4.0 School Bus Literature Background

A literature search for existing school bus related research was conducted to identify up-to-date school bus safety research and to obtain information on available occupant protection systems.

In 1967 and 1972, the University of California at Los Angeles (UCLA), Institute of Transportation and Traffic Engineering, performed research on school bus passenger protection. The researchers tested a variety of restraint options – lap/shoulder belts, lap belts, restraint bars, and air bags – with a variety of dummy types and sizes representing adults and 3-, 6-, and 13-year-old children. In 1967, crash tests were performed using two large school buses which did not meet any Federal motor vehicle safety standards. In 1972, a second set of school bus crash tests was conducted. Again, a variety of restraint types, seat designs, and dummy sizes were included in the vehicles tested. The crash performance and interior design of pre-standard school buses were not comparable to those of post-standard (manufactured April 1977 or later). None of the combinations of seating types was representative of those used in modern school buses.

School bus research reported[5] on in 1976, to (1) develop new design concepts for school bus structures and (2) to develop passive restraints for school bus passengers, served as the basis for the current occupant protection requirements in Federal Motor Vehicle Safety Standard (FMVSS) No. 222, School Bus Passenger Seating and Crash Protection. This research also demonstrated that, in side impacts with a rigid pole, uniform occupant protection was not available in school buses. The report summarized the development of design concepts used for providing occupant protection for school bus passengers. Analysis and development tests indicated the feasibility of providing uniform levels of protection to seated occupants, ranging in size from a 6-year-old child to a 50th percentile adult male in front and rear impacts at 30 mph. The report also summarized the results of a 30 mph side collision of a school bus into a rigid pole.

In 1978, NHTSA reported on a series of sled tests it conducted to obtain additional data in support of rulemaking activities related to FMVSS No. 222. In response to comments received during rulemaking, a sled test program was conducted to evaluate the performance of various production school bus seats. The testing variables included seat spacing, test speed, variable dummy sizes, and seats with and without lap belts. Sled tests were performed at 15 mph and 20

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[5] Development of a Unitized School Bus, Volume 1 - Summary Report, Washington DC, DOTHS-802-004, 1976

mph. Crash performance and interior design of pre-standard school buses were not comparable to those of post-standard school buses.

In 1985, Transport Canada[6] conducted three school bus crash tests. All three school buses were subjected to 30 mph frontal barrier tests. The test vehicles included one large conventional school bus, a medium-sized school bus, and a small school bus. Each bus contained six 5th percentile female dummies. Three of the dummies were restrained with lap belts, and the other three were unrestrained. The test results are summarized in Table 10.

Table 10. Serious Head Injury in Transport Canada Tests

Restraint	**HIC_{36} Large Bus (25,000lbs)**	**HIC_{36} Medium Bus (10,000 lbs)**	**HIC_{36} Small Bus (8,500 lbs)**
Lap Belts	670	1,610	1,970
Compartmentalization	210	710	640
Percent Increase (Lap/Compartmentalization)	**320%**	**230%**	**310%**

Full description: Average HIC_{36} Values for the Transport Canada Tests, by Vehicle Size and Restraint

Canadian study shows lap belts increase head injury for 5th percentile female by 2 to 3 times over compartmentalization.

The test results showed the potential for increased head injury criterion (HIC_{36}) values in frontal collisions when lap belts were used. For the large school bus, the HIC_{36} values for the belted dummies were slightly more than three times higher than the HIC_{36} values for the unbelted dummies. For the small school buses, all HIC_{36} values for the belted dummies exceeded the threshold value for serious injuries of 1,000, and all HIC_{36} values for the unrestrained dummies were less than 1,000. All lap belted dummies experienced severe rearward neck extensions indicating the potential for serious injury.

In 1987, NTSB[7] published a report on 43 serious post-standard school bus crashes that it investigated to determine the crashworthiness of large school buses. This included an assessment of the effects of compartmentalization and seat belt systems. Those crashes included frontal and side collisions and a large number of rollover crashes. For each crash, an evaluation was made to determine whether the use of seat belts would have made a difference in the injury levels of the school bus occupants. NTSB concluded that:

1. Deaths and serious injuries are attributable to being seated at the point of impact,
2. Initial impact preceding a rollover was responsible for higher injury levels,
3. At best, lap belt use probably would have reduced to some degree the injuries of one-third of the 24 school bus passengers who sustained serious injuries and would have made no difference to the majority of occupants,

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[6] School Bus Safety Study - Volume I, Transport Canada, TP6222(E), Jan 1985

[7] Safety Study - Crashworthiness of Large Post-standard School Buses, National Transportation Safety Board, NTSB/SS-87/01

4. At worst, lap belt use would have increased the injuries to almost as many passengers as it would have benefited, and
5. Lap belt use probably would have worsened the outcome for one-fifth of the 58 school bus passengers who sustained moderate injuries.

In 1989, NTSB published a report[8] on 19 post-standard school bus crashes and five crashes involving vans used as school buses that it investigated to examine crash performance. NTSB found that:

1. Occupants of small school buses built after April 1, 1977, fared well in the crashes investigated,
2. Injuries, if any, were generally minor and were primarily to the face, head, or lower limbs,
3. Unrestrained and lap-belted passengers showed similar patterns of minor injuries,
4. Seating position in the bus, more than restraint status, appeared to influence the severity of injuries,
5. First row, lap belted passengers appeared to be at risk from interaction with the restraining barrier in front of the first row of seats, and
6. Lap belts did not appear to hamper emergency evacuation of passengers, primarily because adults on the scene released the passengers from their belts.

In 1987, the Surface Transportation and Uniform Assistance Act contained a provision that directed the National Academy of Sciences (NAS)[9] to investigate the principal causes and injuries to school children riding in school buses, the use of seat belts in school buses, and other measures that may improve the safety of school transportation. Another purpose of the study was to determine those safety measures that are most effective in protecting school children while boarding, leaving, and riding in school buses. The conclusions were as follows:

1. School bus crash tests and sled tests reviewed by NAS did not suggest that lap belts would or would not be effective in frontal collisions,
2. Dummies restrained by lap belts in both tests sustained lower chest injury values but higher head injury values,
3. Benefits of requiring lap belts on large school buses were insufficient to justify a federal requirement for mandatory installation of such belts, and
4. Funds used to purchase and maintain lap belts might be better spent on other school bus safety programs and devices that could save more lives and reduce more injuries.

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[8] Safety Study - Crashworthiness of Small Post-standard School Buses, National Transportation Safety Board, NTSB/SS-89/02

[9] Wootan, Charley, V., et al., Improving School Bus Safety, Transportation Research Board, Special Report 222, Washington DC

5.0 Public Input to Research Process

In response to a 1998 Congressional Conference Report[10], information regarding real-world school bus crash data and safety systems for use on school buses was solicited via a Federal Register notice published on October 26, 1998 (NHTSA-98-4573). The seating systems selected for research and testing had to meet certain considerations such as their potential for improving safety, retaining seating capacity, impact on small businesses, costs, etc., for inclusion in the research program. The most significant comments are presented by category.

5.1 Public Input Regarding Restraint Systems

Busbelts Development Corporation (Busbelts) requested participation in the research program. Busbelts indicated that it had developed a 3-point integrated restraint system that retrofits to existing school bus seats.

AmSafe Commercial Products requested that their air bag/lap belt restraint system be included in the research program. AmSafe indicated that the air bag is an integral part of the lap belt system. It deploys up from a mounting location in front of the occupant, into the space between the forward seat back to provide cushioning in crashes.

Thomas Built Buses, Inc. (Thomas), requested that the effects of spacing be evaluated when testing seat belt assemblies while using belted and unbelted dummies. Thomas noted concerns over the interaction between belted passengers in one seat and passengers in the seat behind them who are not belted. This company asked that various scenarios be considered for new and/or advanced restraint systems under the research program for a thorough evaluation of the restraint system and its potential for improving safety.

5.2 Public Input Regarding Changes in Bus Bodies

Two school bus manufacturers (Thomas and American Transportation Corporation) and the State Director of Pupil Transportation for the Commonwealth of Virginia (CVA) commented on the issue of increased bus body width. All disagreed with increasing the bus body width in order to maintain current seating capacity while meeting any future occupant protection requirements. They argued that the increased width would cause a hazard on secondary roads.

5.3 Public Input Regarding Real-World Crash Data

Only one commenter, the New York State Department of Transportation Bus Safety Section, Region 8, provided data from its crash database. The Bus Accident Summary Listing contained all recorded bus crashes, including non-school bus crashes, from April 1995 through March 1999. The investigators noted the limitations of their investigations, which resulted in incomplete records, and provided minimal crash and injury information.

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[10] Conference Report on Department of Transportation and Related Agencies Appropriations for Fiscal Year 1998, Report 105 - 313, October 7, 1997, page 68

5.4 Public Identification of Crash Conditions

The Indiana University School of Medicine recommended that NHTSA facilitate the establishment of a national, uniform, and comprehensive data collection system that requires school districts to report all injuries to children resulting from a school bus crash.

The American Academy of Pediatrics (AAP) supported mandatory seat belts and asked NHTSA to expand the scope and time line of NHTSA's Phase I research plan to look at data from other countries that use various types of occupant restraints.

5.5 Public Recommendations Regarding Crash Conditions

AAP recommended that NHTSA perform full-scale rollover, side, rear, and offset frontal tests on school buses. Also, AAP recommended that NHTSA perform non-crash tests, such as, sudden stops, rough roads, etc.

CVA recommended evaluation of small and large school buses and the evaluation of lap belt effectiveness as currently installed in school buses.

6.0 Performance of Buses in Crashes

Based on the analytical results of the statistical crash data, investigation of the real world crashes, and the review of relevant literature, representative real-world environment conditions for large school bus crashes were defined for two full scale crash tests. Two tests were performed – frontal and side impact.

6.1 Frontal Crash Performance

The first crash test was conducted by frontally impacting a conventional style school bus (Class C) into a rigid barrier at 30 mph (48.3 km/h). The impact speed was chosen to ensure that sufficient energy would be imparted to the occupants in order to evaluate the protective capability of compartmentalization, plus provide a level at which other methods for occupant injury mitigation could be evaluated during sled testing. A 30 mph (48 km/h) impact into the rigid barrier is also equivalent to two vehicles of similar size impacting at a closing speed or delta V of approximately 60 mph (96 km/h), which was found to be prevalent in the crash database files.

Figure 1 shows the pre-impact conditions for the test. Figure 2 presents the final resting position of the bus after the impact with the rigid wall.

Frontal Crash Test

Figure 1. Pre-Crash Photograph of Frontal School Bus Test.

As typical of large school bus manufacture, the body of the bus is mounted to the frame rails of the chassis by a series of clips or clamps. As shown in Figure 3, this non-rigid mounting feature allowed the bus body to slide forward approximately 36 inches (92 cm) during impact. This dissipation of impact energy over a longer time duration acted to reduce the interior contact speeds and resulting acceleration levels on the vehicle's occupants.

Frontal Crash Test

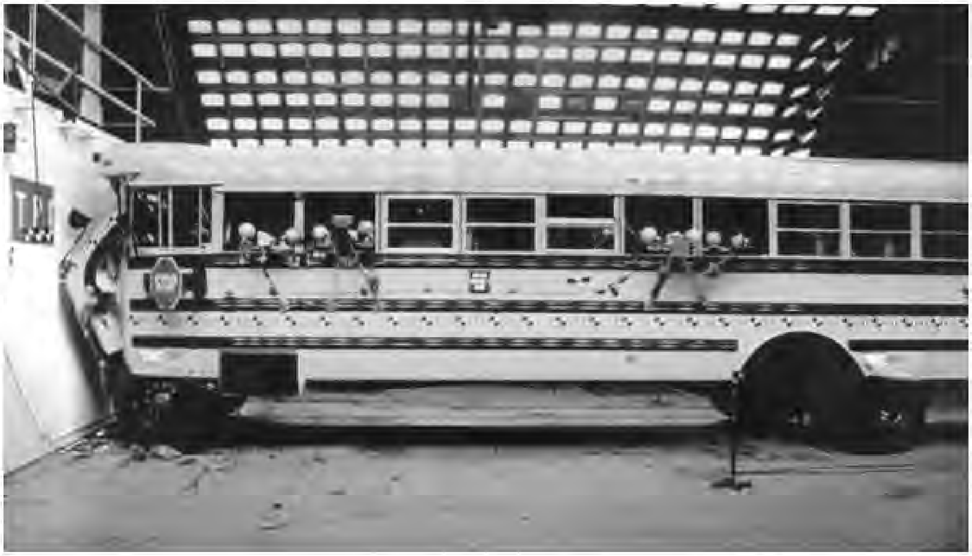

Figure 2. Post-Crash Photograph of Frontal School Bus Test

Frontal Crash Test – Body Slide

Figure 3. Post-Test Photograph of Frontal Test Showing Body to Frame Movement

Hybrid III 50th percentile male (representing adult and large teenaged occupants), 5th percentile female (representing an average 12-year old occupant), and 6-year old dummies were used. Figure 4 shows the dummy seating positions for this test. The dummies were seated so that they were as upright as possible and as rearmost on the seat cushion as possible. There are currently no specific seating procedures for positioning dummies in school bus seats, such as there are in FMVSS Nos. 208 and 214.

Frontal Crash Test – Crash Dummy Placement

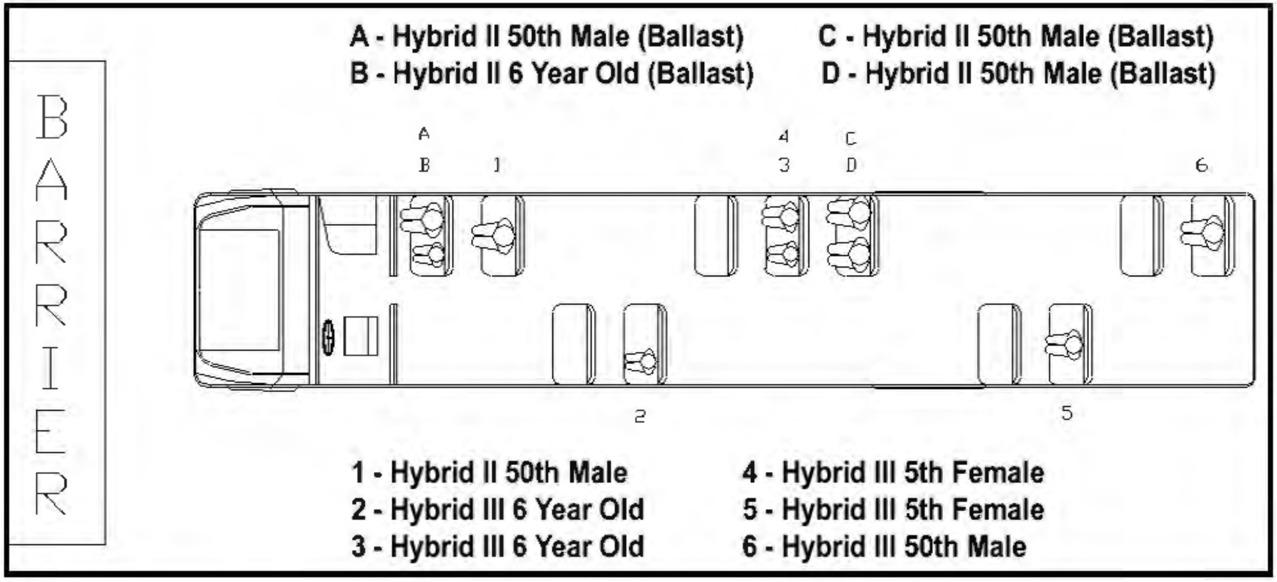

Figure 4. Dummy Location for Frontal Test

Table 11 contains the dummy injury values for the frontal crash tests. The HIC_{15}, Chest G, and Nij values[11] were calculated as specified in the Interim Final Rule for FMVSS No. 208 "Occupant Protection."

Table 11. Frontal Crash Test Results			
Injury Measurement	**Nij**	**HIC_{15}**	**Chest G**
Reference Values	**1.0**	**700**	**60 g's**
Dummy			
#1 (50th M)	0.91	244	26.0
#2 (6 YO)	1.57	93	30.8
#3 (6 YO)	1.07	251	33.0
#4 (5th F)	1.15	104	No Data
#5 (5thF)	1.38	330	22.6
#6 (50th M)	0.84	150	22.3

Accelerometers were positioned along the center aisle of the bus body to record accelerations during the crash. Figure 5 shows the x-axis acceleration time histories for the four locations. Note that all traces are quite similar in shape and peak values. These acceleration time histories were filtered at SAE[12] CFC 60 and re-filtered at CFC 6 to eliminate the high frequency content introduced by the sheet metal floor and to give a relatively smooth trace that can be replicated with the sled.

One of the objectives of the full-scale tests was to establish the crash pulse for use in subsequent sled tests. The crash pulse describes the general shape of the vehicle deceleration during a crash and is depicted in the next two figures. Hence using these data as a reference, NHTSA procured a metering pin which is used to control the acceleration of the HYGE sled. The sled's acceleration pulse is shown overlaid with the bus's center of gravity pulse (circle symbols) in Figure 6. The sled pulse agrees very well with the time duration (approximately 210 milliseconds) and the peak acceleration (approximately 12-13 g's), showing validation between the full-scale test and the sled tests.

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[11] HIC_{15}, chest G, and Nij values are used to predict injury risk in frontal crashes. HIC_{15} is a measure of the risk of head injury, chest G is a measure of chest injury risk, and Nij is a measure of neck injury risk. The reference values for these measurements are the thresholds for compliance used to assess new motor vehicles with regard to frontal occupant protection during crash tests, FMVSS No. 208. For HIC_{15}, a score of 700 is equivalent to a 30 percent risk of a serious head injury (skull fracture). In a similar fashion, chest G of 60 equates to a 20 percent risk of a serious chest injury and Nij of 1 equates to a 22 percent risk of a serious neck injury. For all these measurements, higher scores indicate a higher likelihood of risk. For example, a Nij of 2 equates to a 67 percent risk of serious neck injury while a Nij of 4 equates to a 99 percent risk. More information regarding these injury measures can be found at NHTSA's web site (http://www-nrd.nhtsa.dot.gov/pdf/nrd-11/airbags/rev_criteria.pdf).

[12] SAE J211; Channel Frequency Class (CFC) 60 is commonly referred to as a 100 Hz filter, while CFC 6 is referred to as a 10 Hz filter.

Frontal Crash Deceleration

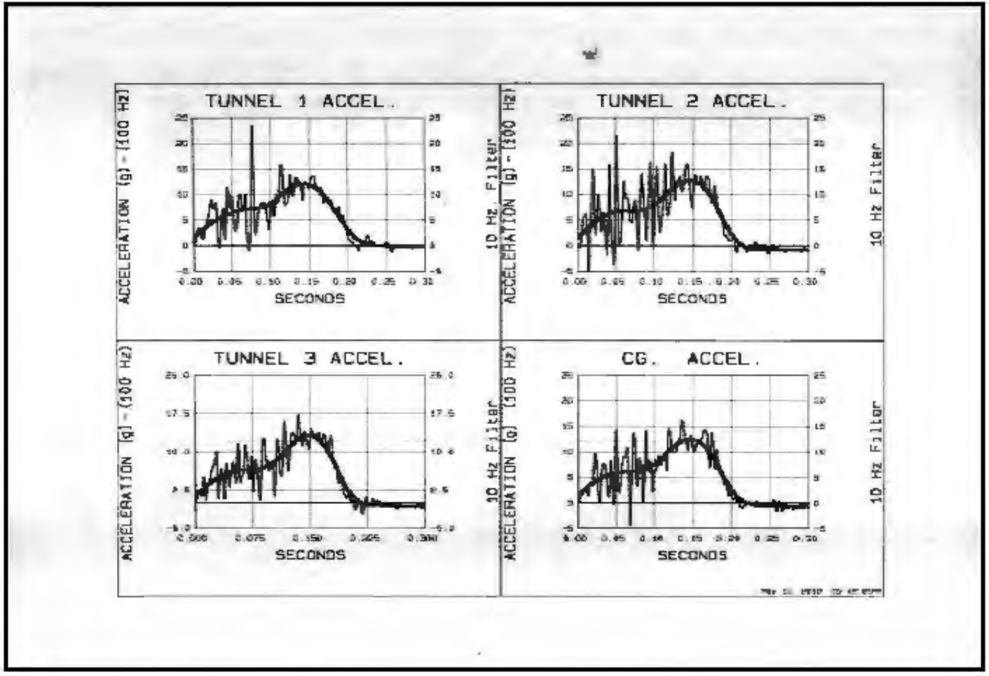

Figure 5. Longitudinal Deceleration Profiles at Different Locations on the Bus

The leveling off of the acceleration pulse of the crash test from about 40-90 milliseconds is a result of the bus body sliding along the chassis. The sled's "metering pin" did not exactly replicate this plateau, producing somewhat higher acceleration in this zone. This resulted in a slightly higher velocity change (delta-V). Delta-Vs for the sled tests were about 35 to 37 mph.

Sled Pulse Compared to Bus Test

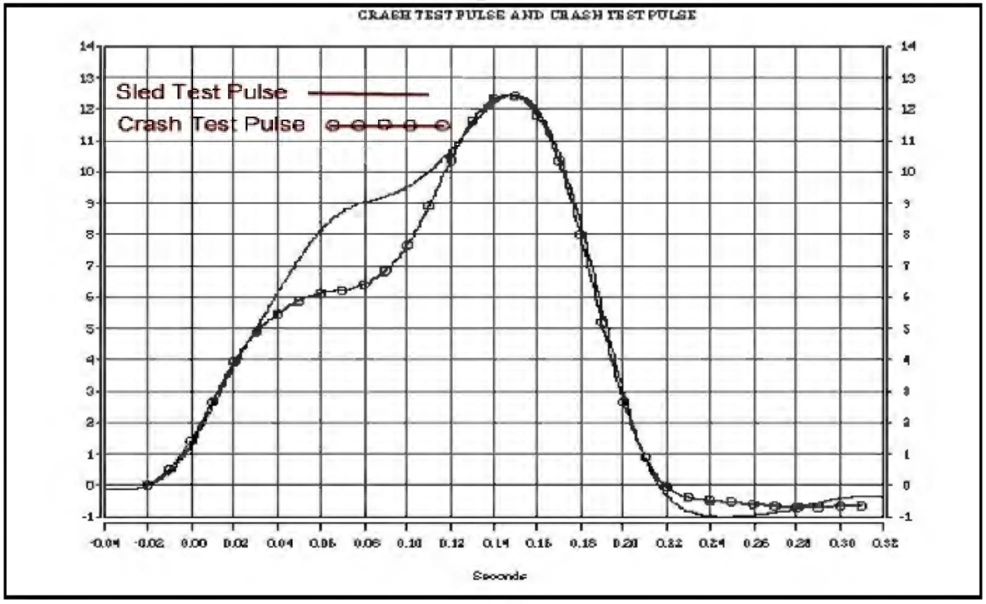

Figure 6. Crash Test Deceleration Pulse with Sled Pulse Overlay

6.2 Side Crash Performance – Heavy Truck into Side of School Bus

The second crash test was conducted by towing a 25,265-pound (11,406 kg) cab-over truck, at 45 mph (72.4 km/h) and 90 degrees, into the side of a transit style school bus (Class D). The school bus was stationary at time of impact. The impact point was chosen such that the left front edge of the truck was directly behind the front axle of the school bus to eliminate contact with rigid structures (such as, axle, tires, etc.) during the initial penetration of the truck into the bus body. Figure 7 shows the pre-impact positioning of the heavy truck relative to the side of the school bus.

A post-impact photograph showing the post-crash positions of the school bus and truck is contained in Figure 8. During impact, the truck penetrated the bus side approximately half way into the compartment, and remained engaged while rotating 180 degrees before coming to a stop. The front axles were severed from both vehicles as seen in Figure 8.

Side Crash Test

Figure 7. Pre-Test Photograph of Side Impact School Bus Crash Showing Bullet Truck

The seating positions of the dummies are shown in Figure 9. As in the frontal crash tests, the Hybrid III 5th percentile female and 6 year old dummies were used. Two 50th percentile male Side Impact Dummies (SID) which are capable of measuring lateral chest and pelvic accelerations were used in place of the Hybrid III 50th percentile male dummies. One of the 50th percentile side impact dummies (SID) was positioned in a row behind the direct impact zone of the truck (position 2 in Figure 9). One Hybrid II 50th percentile male dummy with a single tri-axial accelerometer array in the head was positioned directly centered at the point of impact to determine "survivability" within the impact zone (position 1 in Figure 9).

Side Crash Test

Figure 8. Post-Test Photograph Showing Final Resting Positions

Table 12 presents the results for the side impact crash test. HIC_{15} values are the same as used in the frontal tests. For the SID dummies, the Thoracic Trauma Index (TTI)[13] is recorded as described in FMVSS No. 214 "Side Impact Protection."

Side Crash Test – Crash Dummy Placement

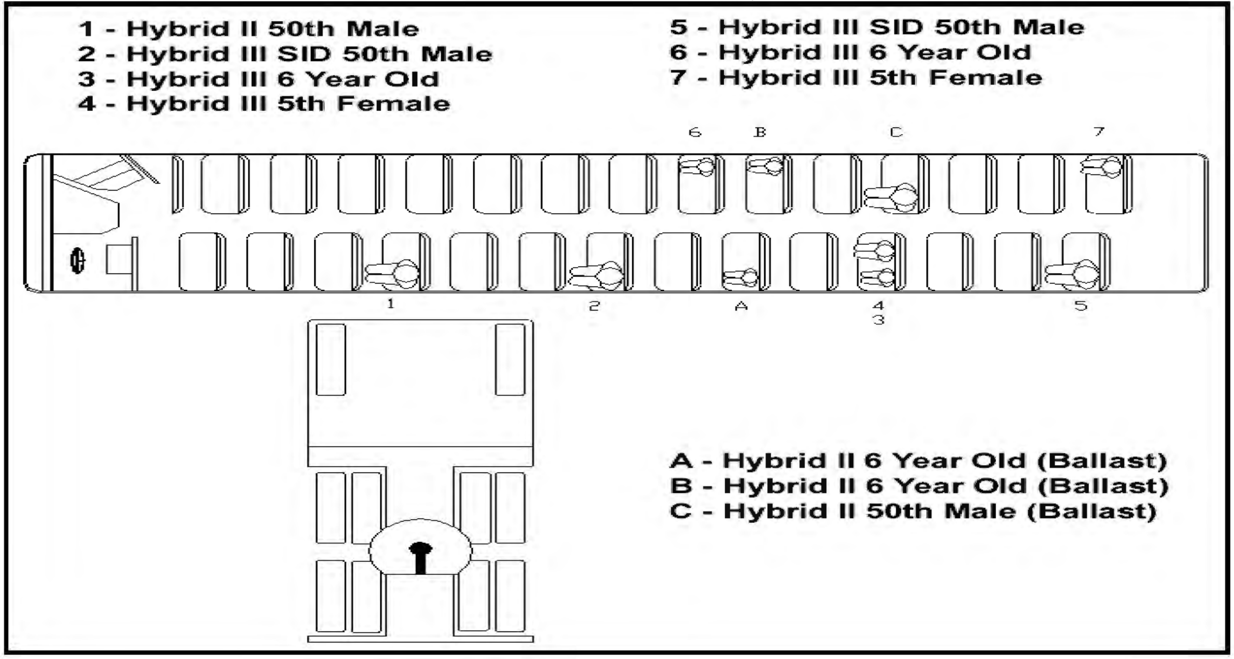

Figure 9. Dummy Seating for Side School Bus Crash

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[13] The Thoracic Trauma Index (TTI) is used to predict risk to injury in side crashes. TTI is a measure of the risk of thoracic injury. The reference value for this measurement is 85 g's for front seat occupants (as defined in FMVSS No. 214) and indicates the onset of serious injuries. As with other dummy injury measures, higher scores indicate a higher likelihood of risk. More information regarding these injury measures can be found at NHTSA's web site (http://www.nhtsa.dot.gov/cars/testing/ncap/Info.html#iq7).

Table 12. Side Impact Crash Test Results

Injury Measurement	HIC_{15}	TTI
Reference Values	**700**	**85 g's**
Dummy		
#1 (H II)	2,164	N/A
#2 (SID)	275	54.7
#3 (5th F)	85	N/A
#4 (6 YO)	124	N/A
#5 (SID)	133	6.1
#6 (6 YO)	54	N/A
#7 (5th F)	1	N/A

Side impact dummy very near impact zone predicts very small chance of thoracic injury.

The dummy in the impact zone measured the highest HIC. All other dummy measurements were well within the reference values. SID #2, which was placed very near the direct impact zone, had a TTI value of 55, which indicates a 5 percent chance of a severe thoracic injury.

Accelerometers were positioned along the length of the school bus. Figure 10 shows the acceleration time histories overlaid for this test. At the center of impact, the peak lateral acceleration was 72 g's. Acceleration levels drop significantly away from the point of impact. This is largely due to the amount of deformation that occurred at the point of impact. This deformation acted to absorb/dissipate much of the energy that would otherwise have been transmitted to the occupants of the bus.

Side Crash Test Acceleration

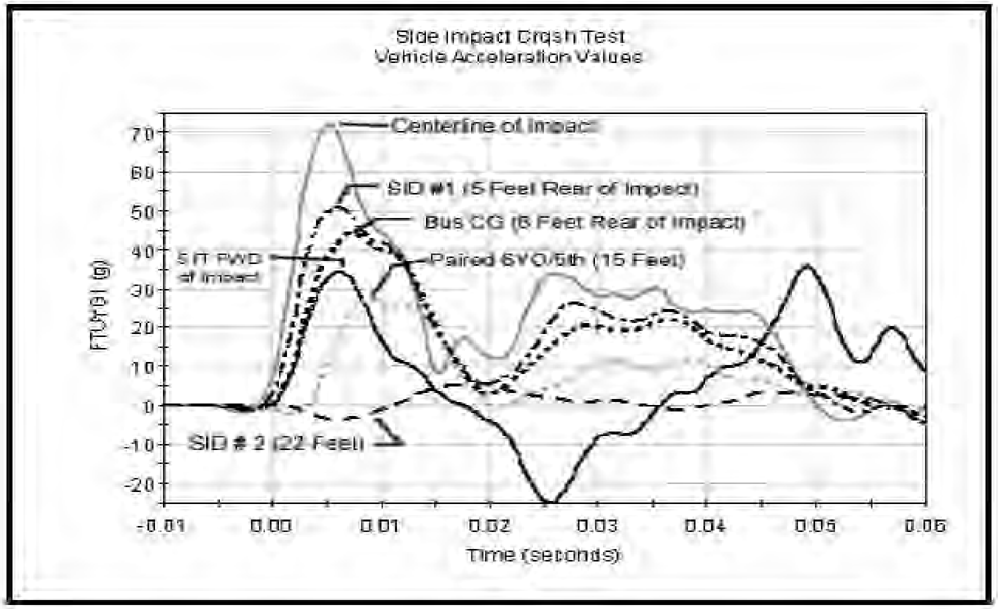

Figure 10. Side Impact School Bus Acceleration at Various Locations in the Bus

Unlike the frontal crash, no single pulse is fully representative of the range of vehicle responses observed in the side impact crash. Generally, all accelerometers measured an increasing level of acceleration with the peak occurring in the 50 to 75 milliseconds range. The magnitude of the peak acceleration was directly related to the proximity of the accelerometer to the impact point, with the accelerometer directly in line with the impacting vehicle's centerline registering the highest.

7.0 Laboratory Testing of School Bus Seating Systems

Sled tests were conducted to replicate the acceleration time history of the school bus full-scale frontal impact test. The following presents a discussion of this portion of the program.

7.1 Laboratory Test Matrix and Equipment

Sled tests were conducted using two different test bucks to evaluate bus safety restraint systems. The first test buck was fabricated by mounting a section from the body of the school bus on the sled. This was done to assess the degree of deformation/energy absorption by the bus floor and its interaction with the seats, and to assess any potential for occupant interaction with portions of the interior other than the seats themselves. The finished test buck is shown in Figure 11. The bus body section contained three rows of seats on both the right and left side of the center aisle. This allowed for testing a maximum of 2 rows of dummies per test.

Sled Buck

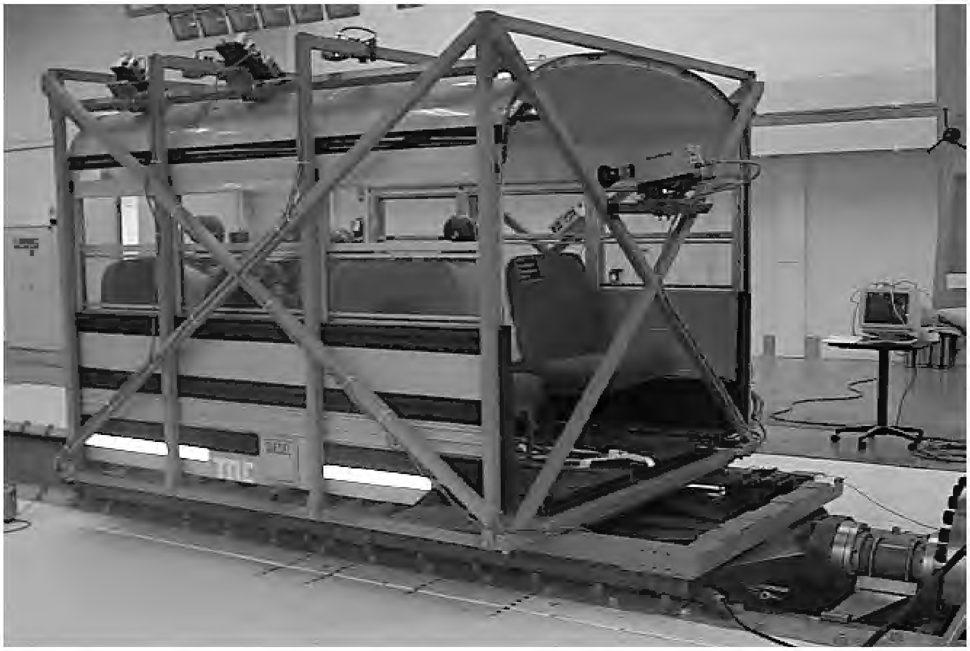

Figure 11. First Sled Buck used in Simulating Frontal Crashes

Testing with the first sled buck showed that there was no significant interaction between the dummies and the walls or ceiling of the bus shell; but there was some incremental damage to the floor of the bus shell from loading by the mounted bus seats[14]. Thus an open frame, rigid floor, sled buck was used to provide a more consistent test platform. It allowed for better high speed imaging of the test event, which resulted in better analyses of the dummies and their interaction with the bus seats and restraint systems. Figure 12 is a photograph of the modified sled buck used in the second test series.

Sled Buck

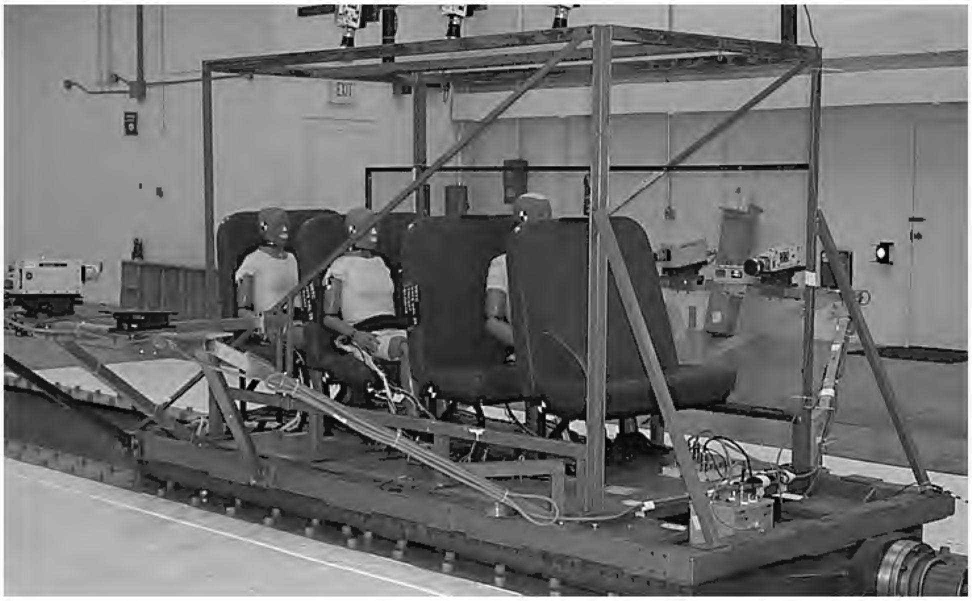

Figure 12. Second Sled Buck used in Frontal Crashes

The sled tests were designed to evaluate occupant size, restraint strategies, loading conditions, seat spacing, and seat back height. The occupant sizes of interest were:

1. **Average 6 year old**: represented by the Hybrid III 6 year old dummy 44.9 in/51.6 lb (114 cm/23.4 kg),
2. **Average 12 year old**: represented by the Hybrid III 5th percentile female dummy 59.1 in/108 lb (150 cm/49 kg), and
3. **Large high school student**: represented by the Hybrid III 50th percentile male dummy 69 in/172.3 lb (175.3 cm/78.2 kg).

Three different restraint strategies were evaluated:

1. **Compartmentalization,**
2. **Lap belt** (with compartmentalization), and
3. **Lap/shoulder belts** on a bus seat with a modified, non-FMVSS 222-compliant seat back.

Other conditions were evaluated:

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[14] The deformation was very small for any single test and accounted for an insignificant amount of energy absorbed by the seats during the crash simulation.

1. Seat spacing,
2. Seat-back height, and
3. Rear occupant loading.

Seats from two manufacturers – Thomas Built Buses, Inc (Thomas) and Blue Bird Corporation (Blue Bird) – were selected for the testing of the compartmentalization concept. These were chosen since these companies are major producers of school bus seats, and since the seats were readily available. For the lap belt only tests, seats and belts were purchased from Thomas. These production seats had additional reinforcement in the seat bench to withstand the loading through the lap belt, while the seat back was identical to the standard Thomas seat. These were selected to provide a direct comparison to the standard Thomas seat being tested for compartmentalization, and since they were readily available. For the lap/shoulder belt tests, seats from two manufacturers – Busbelts Development Corporation (Busbelts) and The C.E. White Company (CE White) – were chosen. The manufacturers modified the backs of these seats to withstand the additional loading imposed by the restrained torso through the shoulder belt. These seats were selected for use in this program since these companies expressed interest in participating, and since the seats were available. The Busbelts seat was a commercially available production seat, while the CE White seat was a prototype seat that they made available to the agency for testing.

Tests were conducted with the seats spaced apart by 19 (48 cm), 22 (56 cm), and 24 inches (61 cm). Seat spacing was determined by measuring from the H-pt. of the SAE 3-dimensional H-pt. point machine to the back of the seat located in front of the dummy. This value was selected based on information obtained from FMVSS No. 222 compliance test data. FMVSS No. 222 allows a maximum seat spacing of 24 inches (61 cm). While 19 to 22 inches (48 to 56 cm) is the range observed for most seats spacing from the available data, 19 inches (48cm) was the minimum seat spacing that readily allowed the normal seating of a Hybrid III 50^{th} percentile male dummy.

The last factor evaluated was the loading conditions on the occupants. Three different conditions were simulated as shown in Figures 13, 14, and 15.

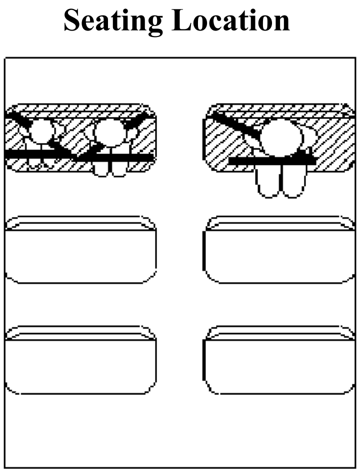

Figure 13. Restrained Occupants Without any Loading from Occupants Seated Behind Them

Seating Location

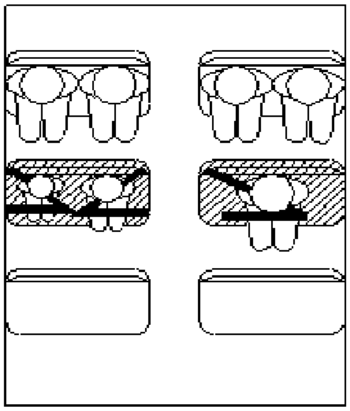

Figure 14. Restrained Occupants With Loading From Occupants Seated Behind Them

Seating Location

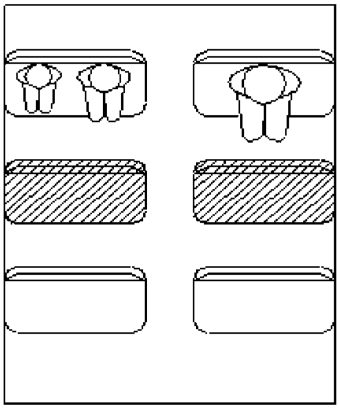

Figure 15. Unrestrained Occupants Into Seat Back in Front of Them

7.2 Dummy Motion Analysis

The motion of the occupant in the seat and the interaction with the seat back and seat restraints are important factors in determining the type, mechanism, and potential severity of any resulting injury. In order to understand the relative effects of seat spacing and seat back height on potential injury it is important to understand the kinematics or dummy motion during the crash event.

Each dummy was initially seated in a normal upright position with the back of the dummy against the seat back. For the 50th percentile male and 5th percentile female dummies, the feet were placed flat on the floor. For the 6-year-old dummy, the feet were positioned straight out in front of the dummy (the knees of the 6-year-old did not extend fully out past the edge of the seat bench when the dummy was placed with its back against the seat back). Figure 16 is an image showing the initial positioning of the 6-year-old and 5th percentile female dummies.

7.2.1 Dummy Motions with Compartmentalization Restraint System

With the onset of the test, the dummy slides forward on the bench seat. The dummy remains in an upright-seated position until the knees of the dummy strike the seat back in front of it. At this point the upper torso begins to rotate forward and downward. The dummy's head strikes the seat back, pushing the head backward which bends the neck. Figure 17 is an image taken at 100 milliseconds into the crash event at the point of knee contact.

Pre Test Seating Conditions

Figure 16. Initial Position of the 6-year-old and 5th Percentile Female Dummies

As the dummy continues to slide forward the head and neck are driven rearward in extension. This continues until the shoulders and upper torso of the dummy reach the seat back and reduce loading on the head and neck. During this portion of the event, the knees and legs of the dummy generally slide below the bench of the impacted seat. Figure 18 is an image taken at 150 milliseconds into the event at the point of maximum extension of the neck. The neck injury criterion typically reached its maximum value either shortly after the head impact, or near the point of maximum neck extension. This point of maximum Nij varies from test to test.

As the body continues to slide forward into the seat back, the upper body comes into contact with the seat back. This relieves some of the load on the neck thus limiting the Nij value. Figure 19 is an image in which the knees of the dummy have slid beneath the seat bench and the full chest has made contact with the seat back. In other tests where the knees stay positioned on the seat back, the shoulders of the dummy make contact with the seat back, which limits the extension imposed on the neck.

7.2.2 Dummy Motions with Lap Belt Restraint Systems

The kinematics for a lap belt restrained passenger begins in a similar fashion to that of the unbelted passenger. The dummy initially slides forward in an upright-seated position. This continues until all slack and/or stretch in the belt webbing is removed. A dummy typically slides forward for four to six inches or more before the belt begins to significantly load the pelvis of the dummy. At this point, the upper torso of the dummy begins to rotate forward and downward. Because of the relatively short seat spacing, the head of the dummy struck the seat back in all of the lap belt tests conducted in both test series. Figure 20 is an image captured 150 milliseconds into the event and is analogous to that of Figure 19 for the unbelted dummy.

Compartmentalization Sled Testing

Figure 17. Compartmentalization Test, Knees make Contact with Seat Back at 100 msec

Compartmentalization Sled Testing

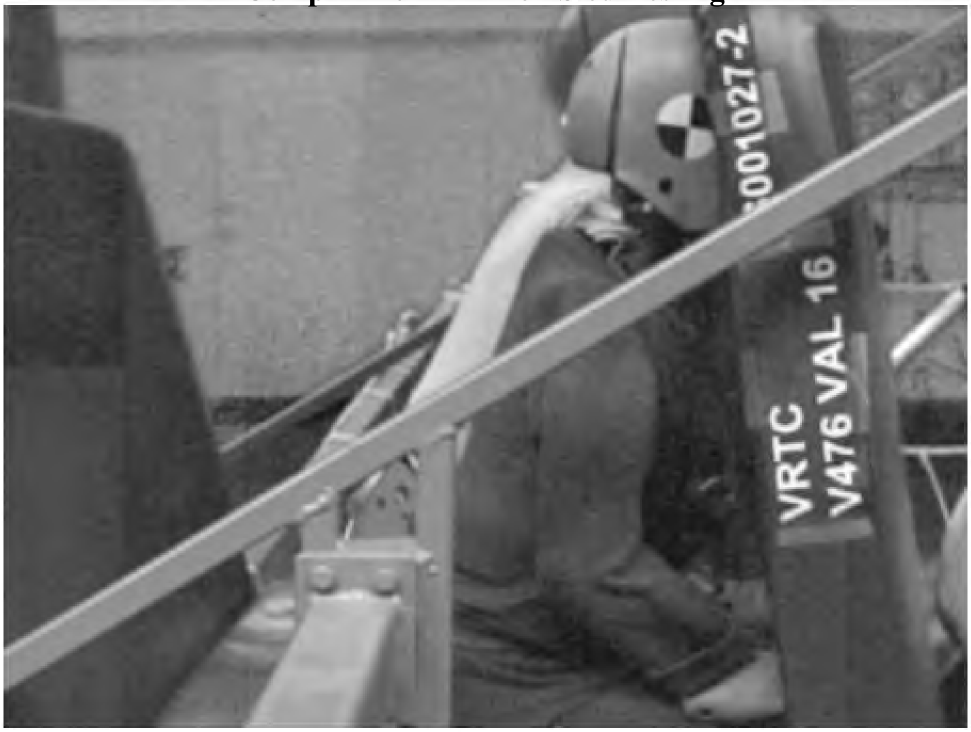

Figure 18. Compartmentalization Test, Upper Body Pivots and Head Contacts at 150 msec

Compartmentalization Sled Testing

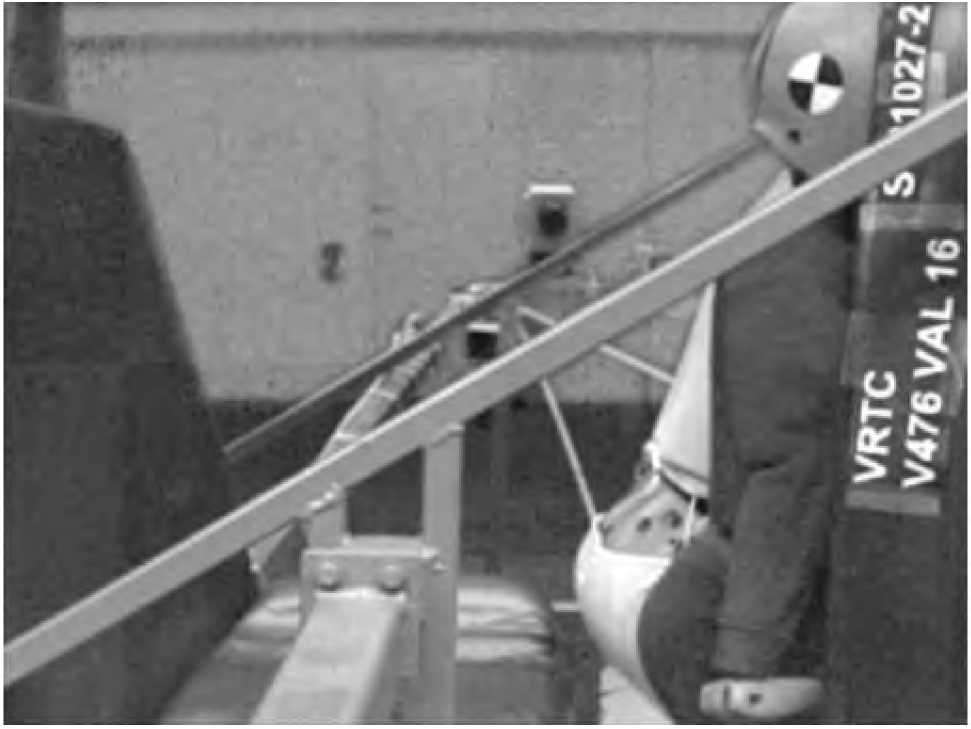

Figure 19. Compartmentalization Test, Upper Body Involvement

A notable difference between the motion of the unbelted and the lap belted dummies is the point at which the forward motion of the dummy stops and torso rotation begins. For the unbelted dummy, this occurs when the knees impact the seat back. For the lap belted dummy, this occurs when the belt becomes taut. This determines when, or if, the upper torso comes into contact with the seat back. For the small 6-year-old dummy, this did not occur in any of the lap belted tests. For the larger 5th percentile female and 50th percentile male dummies, the degree of upper torso involvement, which could have a profound effect on the neck loading, was dictated by seat spacing.

Dummy motion analysis of the 6-year-old dummy motion showed that as the torso pivoted forward, the head made contact with the seat back in all of the lap belt tests conducted. This was true for each of the seat spacing tested for this dummy. Due to the shorter stature of this dummy, contact tended to be high on the head. This orientation of the head at the point of impact and the extent to which the neck had to support the upper torso as it rotated forward had an effect on the amount of neck extension. High speed film analysis of the dummy's motion and interaction with the seat back showed visibly less extension of the neck than seen in some of the tests using the larger dummies. Seat spacing and seat back height appeared to have relatively little effect on the kinematics of the lap belted 6-year-old dummy. As a result, these variables did not appear to significantly affect any of the injury criteria results for the lap belted tests.

7.2.3 Dummy Motions with Lap/Shoulder Belt Restraint Systems

The lap/shoulder belt restraint systems typically prevented head impact into the seat back. The few exceptions with the 50th percentile male dummy resulted in very minor impacts with low resulting injury criteria values. As seen in Figure 21, a 5th percentile female and 6-year-old dummy were restrained properly with the lap/shoulder belt systems. The injury criteria values observed were the results of inertial loading on the head and neck as they snapped forward when the torso was restrained by the restraint system.

Lap Belt Sled Testing

Figure 20. Lap Belt Test at Maximum Neck Extension, 150 msec

Lap-Shoulder Sled Testing

Figure 21. Lap/Shoulder Belt Test at Maximum Neck Flexion

8.0 Laboratory Test Results and Observations

NHTSA conducted 25 laboratory tests, each evaluating one to six dummies. Appendix A presents the test-by-test results for all the sled tests. Thirty-two dummies were tested to evaluate lap/shoulder belt systems. All 32 were used in the 7 data sets – 6-year-old, 5th percentile female, 50th percentile male, 6-year-old misuse case 1, 5th percentile misuse case 1, 6-year-old misuse case 2, and 5th percentile misuse case 2. Misuse case 1 had the shoulder belt placed behind the back, while misuse case 2 had the shoulder belt under the arm.

The average head injury scores (described using HIC_{15} data) are presented in Figure 22. These data are normalized based on a reference value of 700, thus a 700 HIC_{15} is equal to 1 on the chart. Since all the readings are well below 1, the risk for serious head injury is low – around 10 percent. Three lap/shoulder belt configurations are shown in the figures – normal, misuse 1, and misuse 2.

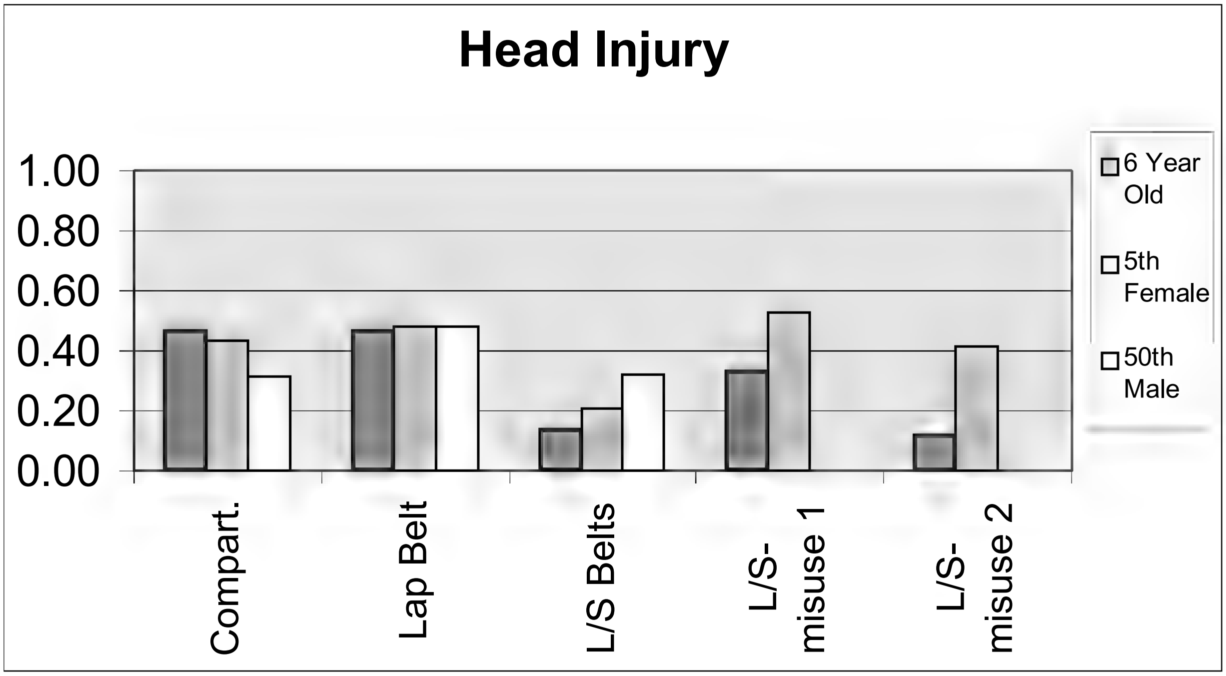

Figure 22. Summary of Average HIC Scores for Sled Tests Simulating Frontal Crashes

The average neck injury scores (denoted using Nij data) are presented in Figure 23. Here dummy readings are above and below the reference value, indicating some conditions have a much higher risk of neck injury than others. For neck injury, a Nij of 1 equates to a 22 percent risk of a serious neck injury while a Nij of 2 equates to a 67 percent risk of serious neck injury.

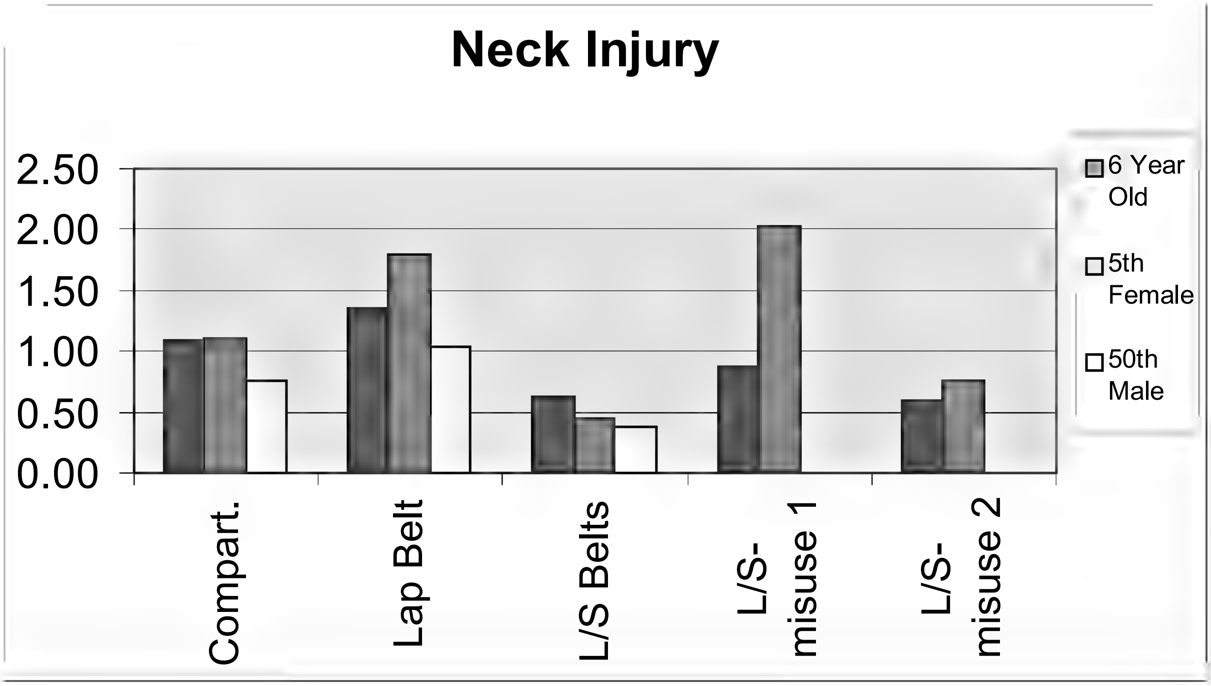

Figure 23. Summary of Average Nij Scores Sled Tests Simulating Frontal Crashes

Twenty-five laboratory tests were conducted utilizing up to 6 dummies per test. Twenty-one dummies were used to evaluate lap belt restraint systems. All but two were used to compute the average data – these two being out-of-position tests of a lap belt system. Forty-three dummies were used to evaluate compartmentalization. Of these 43, 19 were not used in the computation of the average characteristic. Sixteen of these outcomes were dropped because the seats (the three lap/shoulder belt seat systems) in front of the dummy may not have been designed to be compliant with FMVSS 222, while 3 were dropped because the dummy made incidental head contact which was deemed to be not representative of the seat back.

8.1 Compartmentalization Observations

Compartmentalization is the restraint strategy currently used in large school buses (GVWR>10,000 pounds). Since active participation is not required by the passenger to engage the restraint system, it is considered a passive restraint system. This system uses seats that meet specific design and/or performance requirements specified by FMVSS 222. These limit the seat spacing, pad the seat backs to remove hard impact points in the seat back, regulate the dimensions of the seat back, and specify the static force/deflection (i.e., stiffness) characteristics of the seat back when loaded from the rear. This results in padded compartments that contain and protect a passenger in a frontal crash.

8.1.1 Typically Low Head Injury Values for All Dummy Sizes

The head injury criterion used to evaluate these results is the HIC_{15} specified in FMVSS 208, which calculates the maximum HIC_{15} over a timeframe up to 15 milliseconds in duration. The reference value for HIC_{15} is 700 for all three age/size groups of dummies used in these tests.

6-Year-Old Dummy: There were six tests with the 6-year-old dummy that utilized standard seats. The HIC_{15} values for these tests ranged from 107 to 528. Unrestrained impact into the modified seat back design for the original CE White lap/shoulder belt had a HIC_{15} of 937. However, by modifying the padding of the seat back (and making no other changes in the seat back stiffness or structural design of the seat) CE White was able to reduce this HIC_{15} to 82. HIC_{15} proved to be uniformly well below the reference value of 700 for all of the 6-year-old compartmentalized tests. This was true for the modified lap/shoulder belt seat back designs as well as the standard seat back designs.

5th Percentile Female Dummy: The average results were similar for the 5th percentile female dummy. For the eight standard school bus seat tests conducted, the values of HIC_{15} range from 207 up to 484. As seen with the 6-year-old, the original CE White seat back design had a high HIC_{15} (929) but a change in the padding brought this down to a HIC_{15} of 393. The standard high back design had a response similar to that of the standard height seat back design.

50th Percentile Male Dummy: The results are somewhat more complex for the larger stature 50th percentile male dummy tests. The greater stature of this dummy placed the head well above the level of the top of the seat back of standard height. When the dummy slid forward and the torso rotated into the seat back, the head snapped downward, driving the neck (or throat) across the top of the seat back. The head typically did not strike the seat back and the dummy was not fully restrained by the back of the seat just in front of his seat. As the body mass deflected the seat back forward, the dummy exhibited a tendency to slide up and over the top of the seat back with the potential to strike a dummy seated in front of it. This condition resulted in a bimodal outcome in HIC_{15}. If no incidental contact was made (i.e., no dummy was seated in front of the unbelted 50th male or the dummies "missed" each other) the resulting HIC_{15} was typically very low. The few cases in which head contact did occur were glancing blows that did not produce high HIC_{15} values. If incidental contact did occur, then HIC_{15} values tended to be very high. The average HIC_{15} data do not include 2 such cases where the HIC_{15} was nearly 2,000 and a third where the HIC_{15} was over 5,000.

It should be noted that this risk of incidental contact was present only for the standard height seat back. The high back seat configuration effectively prevented the 50th percentile male dummy from overriding the seat back. This was true for both the standard high-back seats as well as the modified high-back seats that used the lap/shoulder belt restraint system. The kinematics of the 50th percentile male's impact into the high back seat configuration was similar to that of the smaller 6-year-old and 5th percentile female, with comparable HIC_{15} results. The modified lap/shoulder belt seat backs produced notably higher HIC_{15} values with several responses over 700 observed. The CE White seats with the additional padding brought these HIC_{15} responses back down to a level comparable to or below that of the standard seats.

8.1.2 Many Neck Injury Values High for Smaller Dummy Sizes

The neck injury criterion used to evaluate these results is the Nij specified in FMVSS 208. The reference value for Nij is 1.0 for all three age/size groups of dummies used in these tests.

6-Year-Old Dummy: The Nij response for the compartmentalized 6-year-old dummy tests ranged between 0.86 and 1.36. The average response for the six standard seats was 1.08, which is slightly above the tolerance limit. The modified seat back of the Busbelts lap/shoulder belt seat design had a Nij value of 1.68. The original CE White design produced a result of 0.75. Addition of the padding for the second test series raised this Nij value to 1.13. The additional padding, while reducing HIC_{15}, increased the Nij value to slightly above the tolerance limit. Three of the six compartmentalized 6-year-old dummy tests conducted on standard seat designs had Nij responses over the tolerance limit of 1.0.

5th Percentile Female Dummy: The neck injury criterion values for the 5th percentile female dummy tests ranged between 0.62 and 1.50 for the standard seat back designs. Only three of the eight compartmentalized tests with standard seat backs had Nij values below the threshold limit of 1.0, with the standard high-back seat design having the lowest response (Nij = 0.62). The lap/shoulder belt modified seat back results were somewhat higher, but comparable to the standard seat backs, while the additional padding of the second CE White design significantly lowered the response value. The original CE White seat produced a Nij of 1.48, while the second CE White seat produced a Nij of 1.07.

50th Percentile Male Dummy: Interpretation of the neck injury criteria for the 50th percentile male dummy is complicated by the kinematics of this dummy with the standard seat back height. As was described with the HIC_{15} results, the stature of this dummy is such that the head was well above the standard seat back height when the dummy was seated in an upright position. When the dummy slid forward the head did not impact the seat back, but rather slid over the top of the seat allowing the neck of the dummy to impact the top of the seat back. Loading on the upper neck load cell (instrumentation used to measure moment and force levels in the neck for Nij calculations) was not particularly severe for this impact condition. As the dummy continued to override the seat back, any incidental contact with a dummy seated in front tended to occur at the top of the head (a spearing motion). This in turn could generate considerable compressive loads down the dummy's spinal column structure, but resulted in fairly low moment and shear loads on the neck. The Nij calculations were typically below the tolerance limit for this dummy size for the compliant standard seat back height. Only one of the ten (only ten tests were used to compute the average for this metric – several were discounted for previously discussed reasons) compartmentalization-configured tests with the 50th percentile male dummy had Nij values above the tolerance limit of 1.0.

8.1.3 Effect of Seat Back Height

The most significant effect of seat back height was containment of the 50th percentile male dummy, as discussed above. Seat back height in general did not appear to have a significant effect on the HIC_{15}. The one standard high back seat design and the three modified high back seat designs used with the lap/shoulder belts resulted in HIC_{15} values well within the range of values seen for the standard seat design.

The single standard high back design test involving the 6-year-old had a HIC_{15} of 250 which was below the mean response for these tests but well within the range of values seen with the standard height seat backs. While this is not sufficient data to draw any significant conclusion, the single standard high back design and the three modified high back designs suggest that seat back height is not a highly significant factor in HIC_{15} or Nij injury criteria for 6-year-olds.

The high-back seat design showed low Nij results for the 50th percentile male dummy tests. The standard high-back test at the 19-inch seat spacing passed with a very low Nij of 0.44 and the 24-inch seat spacing tests had a Nij of 0.37. The modified seat backs of the lap/shoulder belt seats showed varied results as well, with Nij values ranging from 0.59 to 1.45.

In general, for the modified high back seats, the peak Nij values appeared notably later in the crash simulation event. This suggests that the high Nij values were, at least in part, affected by the stiffer structural characteristics of these seats that come into action after a predetermined degree of deflection in the seat back.

8.1.4 Effect of Seat Spacing

Tests were conducted with 3 different seat spacing – 19, 22, and 24 inches. There were no consistent trends observed for any dummy size in the limited number of tests with different seat spacing. With the exception of the three 50th percentile male dummies that overrode the seat backs, the HIC_{15} values for tests with different seat spacing were well within the reference value of 700. Rear loading on the seat by unrestrained occupants did not appear to have a significant effect on the HIC_{15} response level. For Nij, based on a single test, the response of the 5th percentile female increased for the 24-inch seat spacing. There was no trend for either the 6-year-old or the 50th percentile male dummies.

8.2 Lap Belt Restraint – Properly Used

Lap belts are currently required at all seating positions in school buses under 10,000 pounds GVWR. The differences in construction and smaller mass, subject this type of bus to potentially higher acceleration loading in the occupant compartment in a frontal crash. The lap belt restraint requirement was intended to work in conjunction with the compartmentalized seat design.

8.2.1 Keeps Passengers in Seats

A significant advantage of a belt restraint system is its ability to keep a passenger within the protective boundaries of a compartmentalized seat. This can be a potentially significant factor in some rollover and/or secondary impact crash scenarios.

The tendency for the 50th percentile male dummy to override the standard height seat back was not apparent in any of the lap belt tests. The incidental contact by the 50th percentile male seen in some of the standard height seat back compartmentalized tests did not occur in the lap belt tests.

8.2.2 Head Injury Values Are Low For All Dummy Sizes

6-Year-Old Dummy: Figure 22 shows the average results of the three dummy sizes for the lap belt restrained dummies. The 6-year-old HIC_{15} responses were comparable to those for the compartmentalized tests, with values uniformly below the threshold limit of 700. HIC_{15} values ranged from 229 to 497 for the eight lap belt restraint tests conducted. This range of values fell well within the range seen in compartmentalization tests.

5th Percentile Female Dummy: The average HIC_{15} response for the 5th percentile female was comparable to those for the 6-year-old and the 50th percentile male dummies. The range of response values for the 5th percentile female dummy (HIC_{15} = 179 to 495) was comparable to the general range of values seen in the compartmentalized tests.

50th Percentile Male Dummy: The HIC_{15} responses for the five 50th percentile male dummy lap belted tests ranged from 232 to 501. Again this is well within the range of the other lap belted tests and well below the tolerance limit of 700.

8.2.3 Neck Injury Values are High for Most Test Conditions

6-Year-Old Dummy: The neck injury criterion consistently exceeded the reference value of 1.0 for all of the 6-year-old dummy lap belt tests. Nij values range from 1.08 to 1.59. Nij response for the eight lap belt tests conducted was higher than that of the compartmentalization tests (See Figure 23).

5th Percentile Female Dummy: The average Nij response value for the 5th percentile female dummy was higher (See Figure 23) and had a much greater range of responses (Nij = 0.48 to 2.85) than for either the 6-year-old or the 50th percentile male dummies. The highest Nij values observed for this test program occurred with the lap belt tests for this dummy size.

50th Percentile Male Dummy: Two of the 50th percentile male dummy tests into the standard height seat back had very low Nij values (0.67 and 0.47) for the 19-inch and 24-inch seat spacing respectively. The other three tests had Nij values that exceeded the tolerance limit of 1.0. This included a standard height seat using 24-inch seat spacing and two high back seats at 19-inch and 24-inch seat spacing. Overall, the Nij results for the 50th percentile male dummy were higher than for the compartmentalized results.

8.2.4 Neck Injury Results are Sensitive to Seat Spacing/Occupant Size

As noted previously, the 5th percentile female dummy lap belt restraint tests showed an extreme degree of variation in the Nij values. These values ranged from 0.48 to 2.85.

The neck injury criterion was generally high for all dummy sizes tested with lap belts, with 5th percentile female dummies registering the highest followed by 6-year-old dummies. Tests with 19-inch seat spacing produced readings that were somewhat lower than tests with greater seat spacing (22 and 24 inches).

Analysis of the dummy kinematics showed that when the lap belt restrained the forward motion of the dummy, the upper torso rotated forward and downward into the seat back. When the head of the dummy struck the seat back, shear and moment loads occurred in the neck as the torso continued to move forward driving the neck into extension. In the 19-inch seat spacing tests, the shoulders and upper torso made contacts with the seat back. At this point, the shoulders and/or chest of the dummy assumed part of the inertial loading of the upper torso of the dummy. This relieved the loading on the head and neck, reducing the amount of extension and hence the magnitude of the resulting Nij response. With the greater seat spacing, the forward motion of the dummy was arrested at a point that was further away from the seat back. As a result the torso did not make solid contact with the seat back. When this occurred, the neck of the dummy had to dissipate a larger portion of the inertial energy of the upper torso, which resulted in higher shear and moment loads in the neck thus increasing the Nij response.

It should be noted that while the tests conducted for this program highlighted the potential threat of severe neck injury for the 5th percentile female dummy, this potential for injury is not limited to a single age or size. The potential for injury is a function of occupant stature, seat spacing, belt tension and belt stretch. For the belt systems, seat spacing, and dummy sizes that comprised the test configurations for this program, the stature of the 5th percentile female dummy was the most vulnerable to the loading condition with the potential for an injurious neck loading condition. In a real world situation, there will be a range of occupant sizes that will be susceptible to this potential loading condition regardless of the lap belt system or seat spacing that is employed.

8.3 Lap/Shoulder Belt Restraint System – Properly Used

The lap/shoulder belt restraint system is the 3-point restraint system currently employed in passenger vehicles, light trucks, and vans. Two restraint systems were tested for this program – the Busbelts system, currently being marketed as a commercial product and two CE White designs. All of these restraint systems included belt fit systems that allowed the shoulder portion of the belt to be adjusted to comfortably and safely fit a range of occupant sizes.

8.3.1 Keeps Passengers in Seat

Like the lap belt restraint system, the lap/shoulder belt restraint keeps the occupant restrained to the bench portion of the school bus seat. In addition, the shoulder belt of the restraint system keeps the upper torso of the occupant restrained to the seat back of the seat. As a result, there is limited forward rotation of the upper body of the dummy. This limited, or prevented entirely, head impact into the seat back in front of the dummy.

8.3.2 Head Injury Results Are Low For All Size Groups

6-Year-Old Dummy: Figure 22 shows the HIC_{15} results for the three age/size groups. While there was a definite trend towards higher HIC_{15} values with increased dummy size, the averaged results show that the lap/shoulder belt system provided the lowest response levels of the three restraint systems. Eight tests were conducted with the 6-year-old dummy. The lap/shoulder belt system prevented head contact into the seat back in all of these tests. When the restraint system stopped the forward motion of the dummy, the head snapped forward and downward, as shown earlier in Figure 21. The resulting HIC_{15} responses were due to inertial loadings on the head rather than the result of head impact. HIC_{15} values ranged from 59 to 185.

5th Percentile Female Dummy: Similar kinematics and HIC_{15} values were seen with the 5th percentile female dummy. No head impacts occurred with the seat back forward of the seated dummy. The resulting HIC_{15} responses were due to inertial loading that occurred when the dummy's forward motion was restrained by the belt system and the head snapped forward. HIC_{15} values ranged from 49 to 291.

50th Percentile Male Dummy: The stature of the 50th percentile male dummy was such that in one test at the smallest seat spacing, head impact into the seat back did occur. To the extent that the lap/shoulder belt system prevented head impact into the seat back, the resulting HIC_{15} and Nij measurements were due to the inertial loading on the head in the same manner seen with the other two dummy sizes. In the test where head impact occurred, the seat back padding effectively kept HIC_{15} responses at the low levels seen in the compartmentalization and lap belt restraint tests. HIC_{15} responses ranged from 147 to 419.

8.3.3 Neck Injury Values are Low when Restraints Properly Worn

6-Year-Old Dummy: Nij remained below 1.0 for all eight lap/shoulder belt tests. The range of Nij responses ranged from 0.46 to 0.99, with all but one test at or below 0.70. As observed with the head injury criteria, since no head impact occurred for any of these tests, the Nij values were the result of inertial loading of the head driving the neck forward in flexion.

5th Percentile Female Dummy: Very similar results were seen with the 5th percentile female dummy. As noted with the 6-year-old dummy, the lap/shoulder belt restraint system prevented head contact with the seat back in front of the restrained dummy. The Nij responses ranged from 0.17 to 0.69.

50th Percentile Male Dummy: Since the torso of the dummy was restrained by the shoulder belt of the system, the shear and moment loading seen in both the compartmentalization and lap belt restraint tests did not develop, hence the very low neck injury criterion response levels. For the neck injury criterion, Nij ranged from 0.18 to 0.56.

8.3.4 Modified Seat Back – Potential Problem for the Unrestrained Passenger

FMVSS 222 provides performance requirements for seats using the compartmentalization restraint concept. The force/deflection corridor specification was intended to safely restrain and contain a passenger striking the back of the seat in a frontal crash. Since the shoulder belt portion of the lap/shoulder belt restraint uses the seat back as an anchor point, there was a concern that the additional loading on the seat back from the torso of the belted occupant would cause a premature deflection. Thus, there may be insufficient seat back stiffness to effectively restrain the potentially unbelted occupant seated behind the belted occupant.

FMVSS 222 requires that the seat back absorb energy based on the seat capacity, and the seat back not exceed 14 inches of displacement while remaining in predefined force/deflection parameters.

8.4 Misuse of the Restraint System

8.4.1 Misuse of Compartmentalization Restraint Systems

Compartmentalization is a passive restraint system. Misuse of the system is not really possible except in the case where the occupants are out of position in the seat. Examples of this would be an occupant standing or seated sideways with feet in the aisle. While this out of position condition is certainly possible, there is no way to use current Hybrid III dummies to evaluate injury criteria for the types of loading that would potentially occur in these positions. A misuse scenario was not tested for the compartmentalized restraint system.

8.4.2 Misuse of Lap Belt Restraint Systems

Lap belt restraint systems can be potentially misused by placing the restraint too high up on the waist. As a result, the belt rides high on the iliac crest of the pelvic girdle or on the soft tissue of the abdomen. In a crash, the restrained dummy tends to be pushed deeper into the seat cushion by the restraint system allowing the belt to ride up over the pelvic girdle and load the soft tissue of the lower abdomen. This condition is often referred to as "submarining" and presents an increased risk of soft tissue abdominal and spinal injuries.

A single test was conducted with the lap belt restraint placed high on the waist in a misuse configuration for a 5th percentile female dummy and a 6-year-old dummy. The resulting head, neck, and chest injury criteria showed no major increase over the properly fitted lap belt tests. However, the primary threat to injury for this type of belt misuse would be abdominal loading. There is no injury criterion currently available to evaluate the potential for abdominal injury in the Hybrid III dummies. While the misuse of the belt restraint did result in the belt riding up over the iliac crest of both dummies, the resulting increase in potential abdominal injury is speculative.

8.4.3 Misuse of Lap/Shoulder Belt Restraint Systems

There are two very common types of lap/shoulder belt misuse seen among children in passenger automobiles. Children often find the shoulder portion of the restraint system uncomfortable or poorly positioned to their body size and will reposition the shoulder portion of the belt. One common misuse scenario in passenger vehicles is when a child places the shoulder belt portion of the restraint entirely behind their back so that the belt rests on the seat back. A second very common misuse condition is when a child places the shoulder belt under their arm. The belt, which should cross the chest and ride up over the shoulder/collarbone to its anchor point on the seat back (or B-pillar, C-pillar on a passenger vehicle), now crosses lower on the chest and upper abdomen, under the arm pit, and up to the anchor point.

It should be noted that both lap/shoulder restraint systems that were tested had modifications to the standard lap/shoulder belt design that allowed the upper anchorage of the shoulder belt portion to be easily adjusted and thus comfortable and safe to wear for a wide range of passenger sizes. However, the potential for misuse exists and may occur.

Both of these misuse conditions were tested with one of the lap/shoulder belt designs. Tests were conducted using the 6-year-old dummy and the 5th percentile female dummy at the 19-inch and the 22-inch spacing.

With the shoulder belt placed behind the back, the 6-year-old dummy had kinematics very similar to that observed in the lap belt tests. For the 19-inch seat spacing, injury criteria responses were of a comparable magnitude as well (HIC_{15} of 359 and Nij of 1.18). In the 22-inch seat spacing test, the lap belt portion of the restraint prevented head contact with the forward seat back resulting in much lower injury criteria response levels (HIC_{15} of 110 and Nij of 0.56). These values were comparable to those of a properly worn lap/shoulder restraint system.

Head impact occurred for both tests with the 5th percentile female dummy. The resulting HIC_{15} values were comparable to those seen with the 6-year-old dummy using the 19-inch spacing test where head contact occurred, but the Nij values were sharply elevated for both tests (Nij values of 2.13 and 1.92).

When the shoulder portion of the lap/shoulder belt restraint system is misused in such a manner, the restraint system, in effect, becomes a lap belt restraint system. The vehicle occupant is subjected to the same type and magnitude of head and neck loadings as seen with the lap restraint system. This includes the situation in which severe neck loading can occur when the relationship between dummy stature and seat spacing results in the neck supporting the entire load of the upper body of the dummy as it rotates forward into the seat back.

The second misuse condition produced lower HIC_{15} and Nij results. The torsos of both dummies were partially restrained by the shoulder belt. This reduced the severity of the head impacts into the seat back. In addition, the shoulder belt in its misuse position rotated the dummy as it slid forward to engage the belt system. This rotation resulted in considerable lateral loading on the head striking the seat back. This did not have a significant effect on the HIC_{15} results.

The significant conclusion that can be drawn from the restraint misuse tests is that when worn improperly, the lap/shoulder belt restraint system can be potentially as dangerous to the passenger as the lap belt restraint system.

8.5 Other Observations from Laboratory Tests

8.5.1 Low Potential for Chest Injury in Frontal Crash

The primary injury criterion used for evaluating chest injury potential is the 3-millisecond Chest Acceleration as specified in FMVSS 208. The reference value for this criterion is 60 g's for all three of the dummy sizes used in these tests. Figure 24 summarizes the normalized average results of the testing. None of the test results showed any significant threat to injury for any of the restraint systems tested.

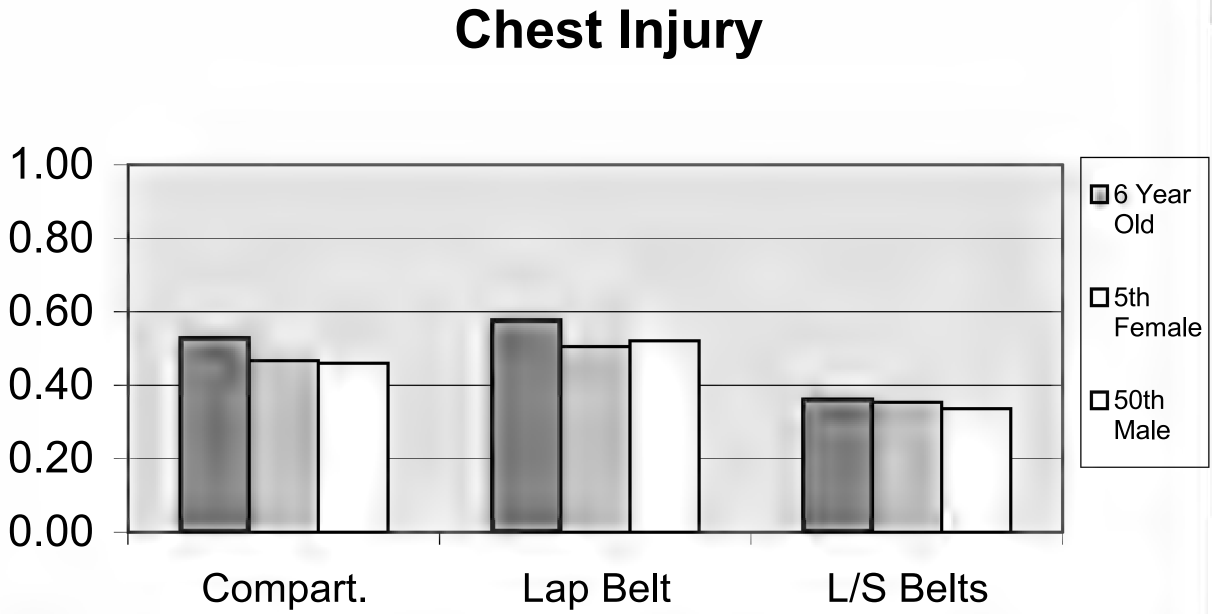

Figure 24. Normalized 3-msec Chest Acceleration for Frontal Sled Tests

The general kinematics along with the closely spaced and padded seat backs provided good protection to the chest for the unbelted occupant in the compartmentalized seat. The lap belt prevented the upper torso from making significant contact with the padded seat back therefore minimizing any potential loading on the chest. The shoulder portion of the lap/shoulder belt restraint system did potentially apply a load to the chest through the shoulder belt portion of the restraint system. However, the relatively low peak acceleration loads within the passenger compartment kept loading on the chest to very low levels.

8.5.2 Low Potential for Leg Injury in Frontal Crash

Injury to the femur is often considered a debilitating rather than life threatening injury, although under very severe loading conditions the femur can be shattered and the ends driven into the abdomen. The Hybrid III dummy is capable of measuring compressive and tensile loading on the femur. The tolerance limit for such loading is 2,250 pounds (10,000 N) for either compressive or tensile loading, per FMVSS 208.

The lap belt and lap/shoulder belt restraint systems restrain the dummy and keeps femur loading well under the pass /fail tolerance limit. The compartmentalized protected dummies showed similar results. The close seat spacing and padded seat backs required to meet FMVSS 222 performance requirements effectively keep femur loading to a non-injurious level.

8.5.3 Concern for Abdominal Loading with Lab Belt Restraint Systems

When properly positioned, lap belts restrain occupants by loading them across the pelvis. When used in conjunction with a shoulder belt, a portion of the load is also distributed across the upper torso. When improperly positioned, due to misfit or misuse, this load 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 available to predict injury if such forces were known. Nevertheless, an attempt was made to measure these loads in the first series of sled tests. An abdominal insert containing load cells was designed (in an in-house development program) and installed in the 6-year-old dummy. Also, iliac crest load cells were installed in the 5th percentile female dummy. The iliac crest load cells measure loading on the pelvis when the belt is properly positioned, but it was believed they would give an indication of possible abdominal loading if the belt were improperly positioned.

The insert used in the 6-year-old dummy was not validated biomechanically, and the design did not prove to be robust. Therefore, its use was discontinued after several tests of the first series, as well as that of the iliac crest load cells in the 5th percentile female dummy. Due to the limitations of these data and to the lack of associated injury criteria, this information was not included in the previous discussions. For completeness, and considering the aforementioned caveats, the average peak loads measured by these load cells are presented in Table 13.

Table 13. Abdominal Measurements

Dummy	Restraint	Load
6-Year-Old	Compartmentalization	100 lbs (444 N)
	Lap belt only	291 lbs (1293 N)
	Lap/shoulder belt	164 lbs (729 N)
5th Percentile Female	Compartmentalization	135 lbs (601 N)
	Lap belt only	758 lbs (3371 N)
	Lap/shoulder belt	308 lbs (1372 N)

Full Description: Average Peak Load Measured in the Abdominal Area

As can be seen, the lap belts produced loads that were nearly three times more than those measured with compartmentalization for the 6-year-old, and over five times more for the 5th percentile female. In comparison, the lap/shoulder belts produced a lower increase of 1.6 to 2.3 times the loads observed with compartmentalization. Thus, it is clear that the potential for abdominal injury exists especially when lap belts are used. The risk of abdominal injury due to these loads remains to be determined.

Further evidence of this potential problem surfaced during the 1998 Bus Crashworthiness Public Hearings held by the NTSB in Las Vegas, NV. During those hearings, Dr. McElhaney, a biomechanical expert from Duke University, indicated that lap belts could seriously injure children, depending on their size, in frontal collisions.

9.0 Research Program Continues in Several Areas

9.1 Additional Restraint Systems to be Evaluated

Three additional restraint systems were evaluated for use in this program, and two of them were selected for sled testing. One of these was another bus seat with an integral lap/shoulder belt, manufactured by Indiana Mills Manufacturing, Inc. (IMMI). The other was an air bag/lap belt restraint manufactured by AmSafe Commercial Products (AmSafe). In this system, the air bag is an integral part of the lap belt and deploys from the belt up into the space between the occupant and the forward seat back. The agency is testing these products since the companies expressed interest, and since they potentially meet the stated criteria for inclusion in the program. The IMMI seat was not available to the agency for testing until Summer 2001, so it was not included in the first two series of HYGE sled tests. Similarly, the AmSafe product was originally designed for use in aircraft, so for school bus applications this system was only in a conceptual stage at the time of their response to the 1998 Request for Comments. Consequently, the AmSafe systems have only recently become available to the agency for testing. Testing and analysis were not completed in time for the results to be included in this report.

***NHTSA is continuing its School Bus research program – looking at alternate restraint systems and side protection methods*.**

The third system was a device called Safe-T-Bar, manufactured by The Majestic Companies, Ltd. This product is similar in concept to the lap bars frequently used in amusement park rides. A padded bar rests on (or near) the lap of the occupant and locks in place during a crash. The agency evaluated this device and decided to not include it in the testing program. While the concept is simple and may be effective for restraining occupants in a low severity environment, such as amusement park rides, it is not an appropriate restraint for higher severity environments, such as bus crashes.

Even when positioned as intended, the Safe-T-Bar will restrain an occupant in a frontal crash by loading through the abdomen. Although current crash test dummies do not measure abdominal loading, it is well established that excessive abdominal loading produces serious and fatal injuries. These types of injuries are seen when lap belts are improperly positioned on the abdomen, rather than across the pelvis, as intended.

By its very design, the device is not “one size fits all,” creating a high potential for misfit and/or misuse. In order to accommodate larger occupants, the Safe-T-Bar must be installed to allow enough space between the rearward edge of the bar and the seat back behind it. This creates a gap that may be too large to effectively restrain a smaller occupant, and it increases the severity of the collision between the child’s abdomen and the bar during a frontal crash. Also, situations such as when smaller occupants are seated next to larger occupants, or when an occupant places a book bag on his/her lap or the seat, can result in the Safe-T-Bar being positioned higher than intended. This would result in direct loading of the chest, neck, or head during a crash.

9.2 Side Impact Protection Research Underway

As discussed earlier in this report, the agency conducted a side impact crash test of a heavy truck into a school bus. Despite the severity of this crash, there was no significant threat of serious injury to the occupants outside the direct impact zone. One dummy was positioned just one row rearward of the incoming truck, and while even the responses from that dummy did not indicate a significant threat of serious injury, they did indicate a chance of minor to moderate injuries to the head and chest.

Therefore, NHTSA has ongoing research to quantify the magnitude of the side impact injury problem to school bus occupants, 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, as directed by Congress, the agency is contracting with Mercer University's Engineering Research Center (MERC) in Macon, Georgia. The objective of the research at MERC is three-fold: (1) develop a finite element model of a typical school bus construction, (2) study the effects on occupant protection of various levels and types of padding added to the bus sidewall and/or roof area, and (3) develop a finite element model countermeasure to address side impact excursion of the seated occupant (e.g., side wings, armrests, etc.), which must consider egress and ingress of occupants.

In conjunction with the research at MERC, the agency's Vehicle Research and Test Center (VRTC) will perform dynamic tests to provide supplemental input and validation data for the sidewall/roof padding model. VRTC has also initiated a program to evaluate the head injury causing potential of the roof, areas surrounding the side windows, and other upper interior structures of school buses. Initial tests were conducted using the free-motion head-form specified for use in Federal Motor Vehicle Safety Standard Number 201. Due to the preliminary nature of these tests, the results are not included in this report.

10.0 Evaluation of Results

10.1 Evaluation of Results from Vehicle Tests

The two crash tests conducted for this program represent severe crash conditions. In general, the mass of school buses effectively minimizes the acceleration forces experienced in a vehicle-to-vehicle crash with most passenger vehicles. The potential acceleration loads from frontal and rear crashes with vehicles of similar mass are also effectively minimized by the manner in which the body of the bus is coupled to the chassis of the bus. The frontal crash test demonstrated that by allowing the body to slide along the frame of the bus, much of the kinetic energy of the bus could be dissipated before loading the passenger compartment.

In a side impact, the construction of the body of the bus does very little to prevent passenger compartment intrusion. However, due to the high ground clearance of the school bus, passenger vehicles are not a serious threat to generate passenger compartment intrusion. Vehicles of sufficient size in which intrusion is a significant probability are of a sufficient mass that no feasible body structural design will effectively mitigate this condition. Passenger compartment intrusion at the point of impact is severe. The high degree of deformation at the point of impact is very effective at absorbing and dissipating the energy of that impact. The side impact test conducted for this program showed that an occupant seated only a few feet outside of the direct impact zone had a high probability of surviving the crash with only minor to moderate injuries.

10.2 Evaluation of Results from Laboratory Tests

Testing indicates that compartmentalization is an effective restraint strategy.

The testing results presented here indicate that compartmentalization is an effective restraint strategy for a frontal crash in school buses. In part, this is due to the relatively low acceleration load seen in even a relatively severe crash condition. The padded seat backs appear to be effective in minimizing the potential for leg and head injury. During the frontal crash, the occupant's kinematics were such that chest loading was not a significant problem. However, these conditions created some degree of risk to neck injury as measured by the injury criterion, Nij. About half of the compartmentalized tests conducted had Nij values over the reference value of 1.0.

For the lap belt system, the risk of head injury was similar to that of the compartmentalized restraint system. This is due largely to the padded compartmentalized seat back that the lap restraint system utilizes. However, the risk of neck injury is increased overall by the use of lap belts. It was found that Nij was highly sensitive to seat spacing and for certain test conditions, the injury criterion could increase sharply by over 200 percent. Motion analysis of the dummy and its interaction with the seat back showed that restraining the hips changed the kinematics of the upper body of the dummy. When the torso of the 5th percentile female dummy was prevented from impacting the seat back, the head and neck supported the entire inertial load of the dummy's forward momentum. This produced the high Nij values observed in some of the tests. While the 5th percentile female dummy highlighted this potential for injury, the condition can exist for a wide range of ages/sizes depending on the particular seat spacing and belt arrangement.

Although the sled testing indicated that lap belts represent an increased risk to neck injury in a frontal crash, the belts keep the passenger within the padded confines of the compartmentalized seat design. They also prevent a larger occupant from overriding a standard height seat back to strike a second passenger seated in front. High back seats were also shown to prevent overriding.

The lap/shoulder belt restraint system performed best overall. This system restrained the upper body and the pelvis of the dummy. As a result, head impact into the seat back was either avoided completely or significantly reduced. The primary loading on the head and neck became inertial loading as the forward motion of the body was halted. The seats deflected and absorbed enough of the deceleration energy that chest loading by the shoulder belt was not significant and the forward snap of the head did not produce significant loads on the head or neck. The adjustable features present on both belt systems tested provided a means for the belt system to safely and comfortably fit a wide range of age/size passengers. When used improperly, the effectiveness of the lap/shoulder belts degraded, resulting in high neck loads, as seen with the lap belts alone.

11.0 Other Considerations for Implementation of Research

In a very good restraint system like compartmentalization in school buses, extreme caution must be taken when considering any changes to the safety equipment that have provided high protection and safety benefits to children for over 24 years. Any change in vehicle safety systems must be weighed against the benefits that could accrue and the negative benefits that could result from those changes.

The results of this research program have shown that lap/shoulder belt systems produce lower dummy head and neck injury measures than compartmentalization and lap belt systems. However, potential negative consequences of lap/shoulder belt systems have not been adequately researched at this time to allow a full determination of overall cost/benefits. This section presents a review of other factors that may need to be considered when improving crashworthiness of school bus vehicles.

11.1 Potential Benefits of Lap/Shoulder Belt Systems

Lap/shoulder belt systems could provide benefits to the passengers of school buses. Based on sled testing, lap/shoulder data indicate potential for fewer injuries in frontal crashes of selected severities, compared to the other two restraint systems (compartmentalization and lap belts). This is especially true for the neck injury, where lap/shoulder belts produced substantially better results in comparison to lap belts and compartmentalization.

Any benefit would require that the belt systems tested in the laboratory function properly in real life crashes. However, real world performance would very much depend upon proper use of these lap/shoulder belt systems. The summary of data used as the basis for this analysis is presented in Table 14.

Table 14. Average Head and Neck Injuries from Sled Tests

Occupant Size	Compartmentalization	Lap belts	Lap/Shoulder Belts
Average HIC_{15} Readings			
6-Year-Old	328	326	96
5th Female	302	334	145
50th Male	220	335	226
Average Nij Readings			
6-Year-Old	1.08	1.35	0.62
5th Female	1.11	1.80	0.44
50th Male	0.76	1.04	0.38

Using established NHTSA methodologies in determining benefits, it is expected that the potential exists for reducing the average passenger fatalities in frontal crashes of school buses from two to one, assuming 100 percent proper use of the lap/shoulder belt systems. While not quantified here, there would also be a companion reduction in the number of injuries in frontal crashes. Additionally, properly used lap/shoulder belt systems have the potential to be effective in reducing fatalities and injuries in other (non-frontal) crashes. Belt systems are particularly effective in reducing ejection in rollover crashes.

11.2 Crash Test Dummies have Limitations

The crash test dummies used in this program did measure abdominal loads. However, NHTSA has not determined the injury mechanisms in real world crashes or established the threshold levels for dummy injury measures to assess the risk of abdominal injuries. Because of these shortcomings, this study did not take into account the abdominal injuries in evaluating the safety performance of these restraint systems. However, data presented in section 8.5.3 indicate lap belt systems generate higher abdominal loads than do lap/shoulder belts and in compartmentalization. It is also noted that biomechanical experts are of the opinion that lap belts have the potential to induce soft tissue injuries to young children in the abdominal region, especially when they are worn slightly above the hipbone.

11.3 Potential Effect of Lap/Shoulder Belt Systems on Bus Capacity

Most school buses have bench seats. The standard school bus bench seat, which is 39 inches wide, is considered a three-passenger seat. As a result, there are thirteen inches of space available for each seat position. Lap belts can accommodate this reduced spacing by placing the anchor points of the center position allowing the belts to overlap. This is not feasible with the more complex anchorage for the lap/shoulder belt system that would require approximately 15 inches per passenger seating position. The width of the seat bench cannot simply be increased to 45 inches without reducing the aisle width to an unacceptable level. Busbelts Development Corporation produces a seat with two lap/shoulder belted seating positions, reducing the potential seating capacity by a third. Alternatively, C. E. White produces both a two-position lap/shoulder belt seat that is 30 inches wide and a three-position lap/shoulder belt seat that is 45 inches wide. These can be paired, yielding 5 across seating, but this seating configuration will reduce potential seating capacity in school buses by 17 percent.

Reduced seating capacity because of lap/shoulder belts in some cases would need to be offset by purchasing additional buses or running more trips with the same bus to provide transportation to all children currently being transported in school buses. If either of these caused a reduction in the number of riders in school buses, benefits gained by installing improved occupant protection devices could be offset as school children find alternative (and less safe) transportation to schools.

11.4 Compatibility of Lap/Shoulder Belt Systems and Compartmentalization

As discussed in the body of this report, the lap/shoulder belt systems tested all had seat back designs that were modified to withstand the combined rear loading from an unrestrained passenger in the seat rearward of the subject seat and the torso loading of the occupant in the subject seat using the lap/shoulder belt in that seat. This modified design has the potential to increase the risk to unbelted passengers because of the potential for stiffer and heavier structure and hard points (such as retractors and anchors) against which occupant contacts could occur. Results of the sled tests indicate the feasibility of using padding to offset this potential problem. While not an overwhelming engineering challenge, consideration will need to given to this issue of safe operation of mixed restraint systems if such mixed systems are allowed in school buses.

11.5 Misuse of Lap/Shoulder Belt Systems

Belt misuse is particularly a valid issue for the lap/shoulder belt system because of the likelihood of placing the shoulder portion of a belt under a child's arm or behind their back when they find it uncomfortable or if the belt systems restrict their movement while seated. The adjustable feature of the lap/shoulder belt systems tested would reduce the potential for discomfort but the potential for misuse still remains. The testing showed that when the shoulder belt was placed behind the back the restraint system functions like a lap belt. As shown in the test program and discussed earlier, the lap belt restraint system can produce a high risk for severe or fatal neck injury.

11.6 Belt Positioning Boosters and Lap/Shoulder Belt Systems

NHTSA is currently evaluating the restraint needs for 4 to 8-year-old children. The agency believes it is important to insure the proper fit of lap/shoulder belt systems in passenger automobiles that may necessitate the use of belt positioning boosters by children. If school buses were outfitted with lap/shoulder belt systems, consideration needs to be given so that the systems are designed to properly fit the entire range of sizes of children that ride school buses or the use of belt positioning boosters, as necessary.

11.7 Lap/Shoulder Belt System Costs

The agency has not conducted a through evaluation of the costs associated with installing lap/shoulder belt systems on school buses. As indicated in Section 2, about 47,000 buses were sold in the 1999-2000 school year. These buses are not uniform in passenger capacity, with the capacity of the A size bus being the least, about 20, to the D size which can range up to 80 passengers. C size buses are the most popular and typically hold 60 to 71 passengers. Assuming that the average seating capacity of the buses sold in a given year is 60, then each year school bus sales account for nearly 3 million passenger seats. In new construction, cost for these systems can be optimized and the agency believes the differential costs would be in the range of 40 to 50 dollars for each seat position, for a total annual cost of 120 to 150 million dollars. The cost to buses less than 10,000 GVWR should be less per seating position, since these vehicles are already equipped with lap belt systems.

12.0 Conclusions Based on Research and Analysis

The following conclusions are based on analysis of school bus crash statistics and a series of vehicle and laboratory tests. These analyses and tests were generally designed to assess current school bus fatalities and injuries associated with frontal crashes as well as the effectiveness of three restraint systems in these crashes.

12.1 Crash Data Analysis

Analyses of the statistical crash data show that school bus occupants are generally well protected. On average over the past 11 years, school buses were involved in about 26,000 crashes per year producing about 10 fatalities (2.5 drivers and 7.5 passengers), about 900 incapacitating injuries, and 7,000 minor injuries. Frontal crashes of school buses, the type these restraint systems are designed to mitigate, average about two fatalities each year. Ejection related injuries would also be mitigated.

12.2 Compartmentalization

- Low head injury values were observed for all dummy sizes, except when override occurred,
- High head injury values were produced when the large male dummy overrode the seat in front of it, while the high-back seats prevented this,
- Significant numbers of child and small female dummy tests had high neck injury values, ranging in the area of approximately half of the tests for each age group,
- Compartmentalization is sensitive to seat back height,
- Compartmentalization does not appear to be sensitive to rear loading conditions, and
- Compartmentalization did show some sensitivity to seat spacing.

12.3 Lap Belt Restraint

- Lap belt restraint systems effectively keep dummies in their seats,
- Head injury values were low for all dummy sizes,
- Neck injury values were high for most test dummies, and were generally higher than those from the compartmentalization tests, and
- Neck injury potential is very sensitive to seat spacing and occupant size, with many tests producing Neck Injury measurements in excess of twice the maximum desirable threshold.

12.4 Lap/Shoulder Belt

- Lap/shoulder belt restraint systems effectively keep dummies in their seats,
- The head injuries were low for all size dummies,
- Head injury measurements were significantly lower than compartmentalization and lap belt results,
- When the restraints were properly worn, the neck injuries were below threshold for all size dummies,
- Restraint misuse – putting the shoulder portion of the belt behind the back or under the arm – can produce undesirable outcomes,
- The stiffer seat back needed for anchoring the shoulder belt portion of these restraints could present a potential problem for the unrestrained passengers seated behind an occupant who is secured with the three-point restraint, and
- Stiffer seat back designs could be addressed by proper design and/or padding of seat through modification of FMVSS 222.

Appendix A. Sled Test Data

Test No	Dummy	Seat	Fwd Seat	Restraint	Spacing	Loading	HIC	Chest g's	Nij	Avg
VAL01	50th M	Thomas Std	Thomas Std	Compt	19	No Load	1843	28.6	0.82	N
VAL01	50th M	Thomas Std	Thomas Std	Compt	19	No Load	5307	20.5	0.69	N
VAL01	5th F	Thomas Std	Thomas Std	Compt	19	1-50th	228	30.9	1.49	Y
VAL01	5th F	Thomas Std	Thomas Std	Compt	19	2-50th	209	33.0	1.03	Y
VAL01	6-YO	Thomas Std	Thomas Std	Compt	19	2-50th	107	31.5	0.93	Y
VAL02	50th M	BB Std	BB Std	Compt	19	No Load	376	38.8	0.82	Y
VAL02	50th M	BB Std	BB Std	Compt	19	No Load	201	35.5	1.54	Y
VAL02	5th F	BB Std	BB Std	Compt	19	1-50th	339	35.8	1.50	Y
VAL02	5th F	BB Std	BB Std	Compt	19	2-50th	404	27.1	1.02	Y
VAL02	6-YO	BB Std	BB Std	Compt	19	2-50th	528	30.4	0.86	Y
VAL03	50th M	BB Std	BB Std	Compt	19	No Load	269	39.5	0.48	Y
VAL03	50th M	Thomas Lap	BB Std	Lap Belt	19	No Load	334	34.4	0.67	Y
VAL03	5th F	BB Std	BB Std	Compt	19	No Load	484	23.5	0.88	Y
VAL03	5th F	Thomas Lap	BB Std	Lap Belt	19	No Load	335	28.9	0.76	Y
VAL03	6-YO	BB Std	BB Std	Compt	19	No Load	369	30.6	1.24	Y
VAL03	6-YO	Thomas Lap	BB Std	Lap Belt	19	No Load	229	48.7	1.40	Y
VAL04	50th M	BB Std	Thomas Lap	Compt	19	No Load	388	28.4	0.87	Y
VAL04	50th M	BB Std	Thomas Lap	Compt	19	No Load	1922	21.0	0.79	N
VAL04	5th F	Thomas Lap	BB Std	Lap Belt	19	2-50th	443	27.9	1.98	Y
VAL04	5th F	Thomas Lap	BB Std	Lap Belt(OOP)	19	No Load	445	23.7	1.10	N
VAL04	6-YO	Thomas Lap	BB Std	Lap Belt	19	2-50th	253	40.5	1.44	Y
VAL04	6-YO	Thomas Lap	BB Std	Lap Belt(OOP)	19	No Load	259	31.9	1.14	N
VAL05	50th M	BB Std	Thomal Lap	Compt	19	No Load	203	24.0	0.85	Y
VAL05	50th M	BB Std	Thomal Lap	Compt	19	No Load	200	23.1	0.91	Y
VAL05	6-YO	Thomas Lap	BB Std	Lap Belt	19	2-50th	497	37.5	1.32	Y
VAL05	6-YO	Thomas Lap	BB Std	Lap Belt	19	No Load	383	33.4	1.59	Y
VAL06	50th M	CEWhite-V1	BB Std	3 Pt	19	No Load	419	19.8	0.36	Y
VAL06	5th F	CEWhite-V1	BB Std	3 Pt	19	No Load	56	21.3	0.33	Y
VAL06	6-YO	CEWhite-V1	BB Std	3 Pt	19	No Load	88	23.1	0.46	Y
VAL07	50th M	BB Std	CEWhite-V1	Compt	19	No Load	551	32.2	0.79	N
VAL07	50th M	BB Std	CEWhite-V1	Compt	19	No Load	766	31.7	0.59	N
VAL07	5th F	CEWhite-V1	BB Std	3 Pt	19	2-50th	291	22.5	0.62	Y
VAL07	6-YO	CEWhite-V1	BB Std	3 Pt	19	2-50th	185	20.4	0.63	Y

Test No	Dummy	Seat	Fwd Seat	Restraint	Spacing	Loading	HIC	Chest g's	Nij	Avg
VAL08	5th F	CEWhite-V1	BB Std	3 Pt	19	No Load	117	22.2	0.30	Y
VAL08	5th F	CEWhite-V1	BB Std	3 Pt	19	No Load	154	20.7	0.53	Y
VAL08	6-YO	CEWhite-V1	BB Std	3 Pt	19	No Load	85	25.0	0.53	Y
VAL08	6-YO	CEWhite-V1	BB Std	3 Pt	19	No Load	89	21.4	0.65	Y
VAL09	5th F	BB Std	BB Std	Compt	22	No Load	324	25.6	0.92	Y
VAL09	5th F	Thomas Lap	BB Std	Lap Belt	22	No Load	495	35.4	2.62	Y
VAL09	6-YO	BB Std	BB Std	Compt	22	No Load	417	33.1	0.96	Y
VAL09	6-YO	Thomas Lap	BB Std	Lap Belt	22	No Load	301	33.9	1.08	Y
VAL10	50th M	Bus Belt	Thomas Std	3 Pt	19	No Load	147	19.2	0.18	Y
VAL10	5th F	Bus Belt	Thomas Std	3 Pt	19	No Load	137	21.6	0.17	Y
VAL10	6-YO	Bus Belt	Thomas Std	3 Pt	19	No Load	81	19.8	0.53	Y
VAL11	50th M	Thomas Std	Bus Belt	Compt	19	No Load	816	22.5	1.13	N
VAL11	50th M	Thomas Std	Bus Belt	Compt	19	No Load	455	23.5	0.84	N
VAL11	5th F	Bus Belt	Thomas Std	3 Pt	19	2-50th	188	26.6	0.57	Y
VAL11	6-YO	Bus Belt	Thomas Std	3 Pt	19	2-50th	90	23.7	0.99	Y
VAL12	50th M	Bus Belt	Thomas Std	3 Pt	19	No Load	204	20.1	0.49	Y
VAL12	50th M	Bus Belt	Thomas Std	3 Pt	19	No Load	218	21.0	0.24	Y
VAL12	50th M	Thomas Std	Bus Belt	Compt	19	No Load	429	21.6	1.43	N
VAL12	5th F	Thomas Std	Bus Belt	Compt	19	No Load	354	35.9	1.55	N
VAL12	6-YO	Thomas Std	Bus Belt	Compt	19	No Load	384	41.7	1.68	N
VAL13	50th M	CEWhite-V1	Thomas Std	3 Pt	19	2-50th	262	23.5	0.33	Y
VAL13	50th M	CEWhite-V1	Thomas Std	3 Pt	19	2-50th	205	21.8	0.40	Y
VAL13	50th M	Thomas Std	CEWhite-V1	Compt	19	No Load	747	31.3	1.12	N
VAL13	5th F	Thomas Std	CEWhite-V1	Compt	19	No Load	929	26.7	1.48	N
VAL13	6-YO	Thomas Std	CEWhite-V1	Compt	19	No Load	937	28.8	0.75	N
VAL14	50th M	BB Std	BB Std	Compt	24	No Load	100	29.1	0.56	Y
VAL14	50th M	BB Std	BB Std	Compt	24	No Load	150	17.6	0.72	Y
VAL14	5th F	BB Lap	BB Std	Lap Belt	24	No Load	368	33.9	2.13	Y
VAL14	6-YO	BB Lap	BB Std	Lap Belt	24	No Load	342	28.4	1.50	Y
VAL15	50th M	BB Lap	BB Std	Lap Belt	24	No Load	336	30.3	0.47	Y
VAL15	50th M	BB Lap	BB Std	Lap Belt	24	No Load	501	25.1	1.29	Y
VAL15	5th F	BB Std	BB Std	Compt	24	2-50th(Restr)	221	27.1	1.43	Y
VAL15	6-YO	BB Std	BB Std	Compt	24	2-50th(Restr)	294	38.3	1.12	Y

Test No	Dummy	Seat	Fwd Seat	Restraint	Spacing	Loading	HIC	Chest g's	Nij	Avg
VAL16	50th M	BB HB	BB HB	Compt	19	No Load	218	16.8	0.44	Y
VAL16	5th F	BB Std	BB HB	Compt	19	No Load	207	21.0	0.62	Y
VAL16	6-YO	BB Std	BB HB	Compt	19	No Load	250	26.7	1.36	Y
VAL17	5th F	BB Lap	BB HB	Lap Belt	19	No Load	185	25.2	0.48	Y
VAL17	6-YO	BB Lap	BB HB	Lap Belt	19	No Load	274	26.0	1.24	Y
VAL18	5th F	BB Lap	BB HB	Lap Belt	22	No Load	179	30.7	2.85	Y
VAL18	6-YO	BB Lap	BB HB	Lap Belt	22	No Load	326	29.3	1.24	Y
VAL19	5th F	CEWhite-V2	CEWhite-V2	3 Pt	19	No Load	49	18.9	0.33	Y
VAL19	5th F	CEWhite-V2	CEWhite-V2	Compt	19	No Load	393	21.9	1.07	N
VAL19	6-YO	CEWhite-V2	CEWhite-V2	3 Pt	19	No Load	92	17.9	0.50	Y
VAL19	6-YO	CEWhite-V2	CEWhite-V2	Compt	19	No Load	82	27.3	1.13	N
VAL20	50th M	CEWhite-V2	CEWhite-V2	Compt	19	No Load	311	20.1	0.66	N
VAL20	50th M	CEWhite-V2	CEWhite-V2	Compt	19	No Load	220	19.0	0.66	N
VAL20	5th F	CEWhite-V2	CEWhite-V2	3 Pt	19	2-50th	164	15.4	0.69	Y
VAL20	6-YO	CEWhite-V2	CEWhite-V2	3 Pt	19	2-50th	59	21.9	0.70	Y
VAL21	50th M	CEWhite-V2	CEWhite-V2	3 Pt	19	2-50th	179	17.2	0.56	Y
VAL21	50th M	CEWhite-V2	CEWhite-V2	3 Pt	19	2-50th	175	18.9	0.47	Y
VAL21	50th M	CEWhite-V2	CEWhite-V2	Compt	19	No Load	306	23.0	1.45	N
VAL21	50th M	CEWhite-V2	CEWhite-V2	Compt	19	No Load	303	18.1	0.84	N
VAL22	5th F	CEWhite-V2	CEWhite-V2	3 Pt(OOP-1)	19	No Load	431	29.3	2.13	Y
VAL22	5th F	CEWhite-V2	CEWhite-V2	3 Pt(OOP-1)	22	No Load	307	31.7	1.92	Y
VAL22	6-YO	CEWhite-V2	CEWhite-V2	3 Pt(OOP-1)	19	No Load	359	32.1	1.18	Y
VAL22	6-YO	CEWhite-V2	CEWhite-V2	3 Pt(OOP-1)	22	No Load	110	30.5	0.56	Y
VAL23	5th F	CEWhite-V2	CEWhite-V2	3 Pt(OOP-2)	19	No Load	282	21.3	0.72	Y
VAL23	5th F	CEWhite-V2	CEWhite-V2	3 Pt(OOP-2)	22	No Load	298	26.4	0.78	Y
VAL23	6-YO	CEWhite-V2	CEWhite-V2	3 Pt(OOP-2)	19	No Load	85	22.5	0.69	Y
VAL23	6-YO	CEWhite-V2	CEWhite-V2	3 Pt(OOP-2)	22	No Load	81	23.0	0.51	Y
VAL24	50th M	CEW-HB	CEW-HB	Compt	24	No Load	97	23.1	0.37	Y
VAL24	50th M	BB Lap	CEW-HB	Lap Belt	24	No Load	270	36.2	1.49	Y
VAL25	50th M	BB Lap	CEW-HB	Lap Belt	19	No Load	232	30.0	1.28	Y

Appendix Notes:

Test Number: sequence number of individual tests

Dummy:

6-YO – 6-year-old
5th F – 5^{th} Percentile female
50th M – 50^{th} Percentile male

Seat & Fwd Seat:

BB Std – Standard seat from a Blue Bird School Bus
Thomas Std – Standard seat from a Thomas Built Bus
CEWhite-V1 – first version of the C. E. White 3-point belt seat
CEWhite-V2 – second version of the C. E. White 3-point belt seat (model with extra padding)
BusBelt – 3-point belt seat from Busbelts Development Corporation
BB Lap – Standard lap belt seat from a Blue Bird School Bus
Thomas Lap – Standard lap belt seat from a Thomas Built School Bus
BB-HB – Standard high back seat from a Blue Bird School Bus
CEW-HB – High-back version of a standard school bus seat manufactured by C. E. White

Restraint:

Compart – Compartmentalization
Lap Belt – 2-point lap belt system
3 Pt – 3-point lap/shoulder belt system
Lap Belt(OOP) – out of position tests using lap belt system
3 Pt (OOP-1) – out of position lap/shoulder belt system with shoulder belt behind back
3 Pt (OOP-2) – out of position lap/shoulder belt system with shoulder belt under arm

Spacing: space between seats in inches, measured from the H-point of a SAE 3-dimensional H-pt machine to the back of the seat located in front of the machine

Loading:

No Load – There were no dummies behind the test dummies or the dummies behind were restrained with lap/shoulder belts
1 50th – there was one 50th percentile male dummy behind the subject dummy or dummies
2 50th – there were two 50th percentile male dummies behind the subject dummy or dummies
2-50th (restr) – there were two 50th percentile dummies behind the subject dummies, but their restraint may have limited the full effect of their loading on the seat in front of them

HIC: 15 millisecond Head Injury Criterion
Chest G: 3-millisecond-clip chest acceleration
Nij: Neck injury

Avg:

Y – these data were used to formulate the figure of merit for the dummy/restraint/injury measurement
N – these data were not used to formulate the figure of merit for the dummy/restraint/injury measurement (see Section 8 for further explanation)