

Crashworthiness Evaluation of Mass Transit Buses

FEBRUARY 2012

FTA Report No. 0021
Federal Transit Administration

PREPARED BY
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National Institute for Aviation Research (NIAR)



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Courtesy of Dr. Gerardo Olivares, National Institute for Aviation Research (NIAR)

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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft³	cubic feet	0.028	cubic meters	m ³
yd³	cubic yards	0.765	cubic meters	m ³
NOTE: volumes greater than 1000 L shall be shown in m ³				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

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FOREWORD

This report summarizes the findings of the Mass Transit Bus Crashworthiness research project conducted from 2005 through 2010 at the National Center for Aviation Research (NIAR), Wichita State University. It is intended to summarize the research findings. More detailed data, including test reports, videos, technical papers, and simulation results, are available at NIAR's project website:

Transit Bus Crashworthiness Data

<https://www.niar.wichita.edu/CompMechPortal/MainMenuCurrentResearchProjects/FTAMassTransitBusCrashworthinessIII/tabid/90/Default.aspx>

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All illustrations and photos in this report are courtesy of Dr. Gerardo Olivares, National Institute for Aviation Research (NIAR), unless otherwise specified.

ABSTRACT

Mass transit bus systems are an integral part of the national transportation network, serving more than 20.6 billion passenger-miles per year with a relatively low fatality rate. Bus occupant injuries are evenly distributed among crashes on all sides of the bus, while fatalities primarily result from frontal crashes. The three primary objectives of this crashworthiness research were to (1) characterize the structural response of mass transit buses, (2) characterize the occupant kinematics and injury mechanisms in mass transit bus interiors, and (3) develop interior design concepts and crashworthiness design procedures for mass transit buses. For better understanding of how injuries and damage result from bus crashes, this research used computational and virtual reality methods to model crash effects on buses and their occupants and full-size sled tests with “crash dummies” of varying sizes to verify the simulation results. The research found that primary mechanisms of injury to occupants are passenger-to-passenger collision and passenger-to-seat-structure impact. The research suggested design guidelines that should reduce occupant injuries and fatalities during side, frontal-, and rear-impact collisions of transit buses with various vehicle types.

Objectives

The primary objectives of this research into what happens to transit bus passengers during crashes were to (1) characterize the structural response of buses, (2) characterize how passengers are injured when they collide with other passengers and bus fixtures, and (3) develop interior design concepts and crashworthiness design principles for safer mass transit buses.

Research Methods

For better understanding of how injuries and damage result from bus crashes, the National Institute of Aviation Research (NIAR) used analysis based on computational and virtual reality methods to model crash effects on buses and their occupants. A detailed finite element model of a typical low-floor transit bus was generated and used to calculate the crash pulses for the passenger compartment in typical frontal, side, and rear crash scenarios. Multibody modeling was also used to help analyze crash dynamics and impact consequences in collisions of transit buses with various vehicle types. These numerical simulation results were verified by a series of full-scale sled tests with a comprehensive set of anthropomorphic test devices (ATD) (“crash dummies”), representing a range of passengers from 12-month-old infants up through 95th-percentile adult males. The sled tests, conducted at NIAR’s Crash Dynamics Laboratory, allowed identification of injury mechanisms to seated and standing passengers and aided in validating numerical models of bus interiors.

Findings and Conclusions

The research found that primary mechanisms of injury to passengers are collision impacts with other passengers and seat structures. It also found that standard seatbacks in mass transit buses are too low to protect against neck injuries and indicated that high seatbacks and headrests would reduce rear impact injuries significantly. Responding to industry concerns that increased seat height would cause a reduction in passenger visibility, NIAR developed a seatback design that provides needed head and neck support while reducing operator-passenger visibility by only 20 percent. Introducing offset seat rows could improve the level of protection to passengers during severe side impacts.

The research suggested design guidelines that should reduce occupant injuries and damage to other vehicles in crashes. For example, the research led to a strong recommendation against side-facing seats for the protection of both the seated passengers in them and standing passengers they would strike in a crash. Similarly, removal of rear center-aisle seats is strongly recommended, eliminating the danger to passengers seated in them and to standing occupants. The current lack of child-specific injury protection could be remedied by adapting automotive child restraint systems for use in transit buses.

Finally, the research led to a strong recommendation for virtual testing and certification of transit buses using numerical modeling. When used in conjunction with experimental static and dynamic testing, numerical modeling allows for an efficient, iterative, cost-effective method to evaluate the crashworthiness behavior

of mass transit buses. With judicious use of validated mathematical models, changing from an over-engineered bus design to a modernized design with lightweight materials and structural components could be achieved using a small fraction of the resources required for traditional experimental techniques involving building and testing full-scale models.

Introduction

Mass transit buses are a significant part of the national transit network. To safeguard the commuting public that uses this aspect of the network to travel nearly 22 billion passenger-miles per year, ongoing investigation of bus crashworthiness is essential. The National Institute for Aviation Research (NIAR), with funding from the Federal Transit Administration (FTA), began studying mass transit bus crashworthiness in order to understand current levels of structural crashworthiness and injury mechanisms and to create guidelines for improvements to bus crashworthiness and methods for improving industry reporting statistics to aid in future research. Research performed to create design concepts for industry crashworthiness standards required a rigorous and comprehensive approach, one that borrowed forward-looking techniques and ideas from the automotive and aircraft industries. This report emphasizes the findings and conclusions of nearly five years of mass transit bus crashworthiness research. A familiarity with the approach and methodology of the research is important in understanding the guidance.

The primary objectives of the project were to:

- characterize the structural response of mass transit buses for typical side, frontal, and rear impact and rollover scenarios
- characterize the occupant kinematics and injury mechanisms in mass transit bus interiors during side, frontal, and rear impact scenarios
- develop structural crashworthiness design procedures and interior design guidelines for mass transit buses to reduce occupant injuries and fatalities during side, frontal, and rear impact collisions with large trucks, light trucks, and compact cars

The secondary research objectives were to:

- characterize the compatibility of crashworthiness features of mass transit buses with large trucks, light trucks, and compact cars
- define exterior design guidelines to address crashworthiness incompatibilities of mass transit buses with large trucks, light trucks, and compact cars

SECTION
2

Technical Approach

NIAR employed a twofold, mutually-informative method of research: an analytical approach involving finite element (FE) and multibody (MB) modeling, and experimental research with a crash sled and anthropomorphic test devices (ATD) in NIAR’s Crash Dynamics Laboratory. This dual testing/modeling approach provides better insight than either approach alone and makes the best use of the available funding since full-scale crash testing is time-consuming and expensive.

Accident Data Analysis

At the time of this research, transit bus usage, in terms of passenger-miles, averaged 20.6 billion miles per year. In the years since the initial literature review, through 2008, the number of passenger-miles per year has averaged 21.9 billion. From 1992–2002, transit bus ridership increased by 11 percent in terms of unlinked trips and increased another 5 percent from 2002–2008. Also, from 1990–2002, the number of transit motor buses in the U.S. increased by 30 percent. According to the Traffic Safety Facts (TSF) reports from 1999–2003, an average of 40 fatalities and 18,430 injuries of bus occupants occurred per year. In the TSF reports, buses are defined as “large motor vehicles used to carry more than ten passengers, including school buses, inter-city buses, and transit buses.” Results from the TSF, relevant to the mass transit bus industry, are summarized in this section.

1999–2003 Traffic Safety Facts—Vehicle Synopsis [1]

TSF reports contain data regarding crash origin, sustained injuries, and accident fatalities. Those data related specifically to vehicle crash type and whether the crash resulted in injuries or fatalities are summarized in Table 2-1. According to the vehicle synopsis, crashes that resulted in a fatality were predominantly those with a frontal point of initial impact. The points of initial impact were more evenly distributed in crashes that resulted in injuries but not fatalities.

Table 2-1
Crash Type in Bus Crashes with Fatalities and Crashes with Injuries Only

Type of Crash	Percentage of All Crashes Resulting in a Fatality	Percentage of All Crashes Resulting in Injuries
Frontal impact	64%	37%
Rear impact	16%	25%
Side Impact	14%	36%
Rollover	<3.1%	<0.1%
Fire occurrence	<0.3%	<0.05%

While the TSF reports makes no distinction between the types of bus involved in a particular crash, they do contain more general statistics for fatal accidents. Table 2-2 is a breakdown of bus types involved in crashes that resulted in a fatality.

Table 2-2

Bus Type Related to Crashes Resulting in a Fatality

Type of Bus	Percentage of All Crashes Resulting in a Fatality
Mass transit bus	36%
School bus	38%
Intercity bus	9%
Other bus type	11%
Unknown	6%

1999–2003 Traffic Safety Facts—Occupant Synopsis [1]

During the span of TSF reports studied, an average of 40 bus occupants were killed and 18,430 were injured per year. Turning broad TSF reports into relevant, discrete information regarding mass transit bus crash data was a challenge. Table 2-3 further summarizes extracted data regarding fatalities and injuries among bus and partner-vehicle occupants in bus crashes involving one other vehicle, which account for a significant portion of bus crashes that resulted in a fatality. For example, 68 percent of bus occupant injuries occurred during crashes involving two vehicles.

Table 2-3

Bus Type Related to Crashes Resulting in a Fatality

Type of Vehicle Occupied	Fatalities	Injuries
Mass transit bus	11	12,000
Partner vehicle	162	8,800
Passenger car	(102)	(6,000)
Light truck	(49)	(2,800)
Motorcycle	(9)	
Large truck	(2)	
None	58	
Pedal cyclist	(9)	
Pedestrian	(49)	

In general terms, the causes of fatalities in bus-related crashes are summarized in Table 2-4.

Table 2-4

Causes of Fatalities in Bus-related Crashes

Cause of Fatality	Percentage of Bus related Fatalities
Occupant ejection	28%
Non-ejection fatal impact	53%
Unknown	19%

Also, considering that TSF makes no specific distinction between bus types on a per-case level, Table 2-5 shows that mass transit buses accounted for the lowest percentage of all fatalities and injuries resulting from bus crashes.

Table 2-5

Distribution of Fatalities and Injuries by Type of Bus Involved

Type of Bus	Percentage of All Fatalities	Percentage of All Injuries
Mass transit bus	14%	23%
School bus	24%	40%
Intercity bus	30%	24%

Numerical Modeling with Finite Element and Multibody Models

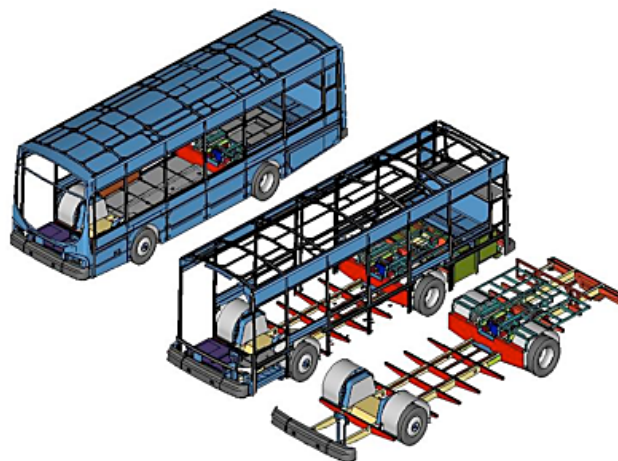
Numerical modeling, with nonlinear FE analysis, is now an essential design and development tool. Computational models are increasingly replacing testing of prototypes in the automotive industry to reduce time in vehicle development cycles and associated costs. Simulated testing, using FE and multibody techniques, was carried out to evaluate the structural response of the vehicles and the injury mechanisms to occupants.

The FE model shown in Figure 2-1 was validated for various crash conditions specified in the Standard Bus Procurement Guidelines (SBPG), as summarized in the paper cited in reference [2]. The model was validated specifically for:

- Frontal impact conditions, per SBPG section 5.4.3.9.2 [7]
- Side impact conditions, per SBPG section 5.4.1.2 [7]
- Rear impact conditions, per SBPG section 5.4.3.9.2 [7]
- Roof strength requirements per, SBPG section 5.4.1.2 [7]

Figure 2-1

Mass transit bus finite element model section views



Source: Olivares [2]

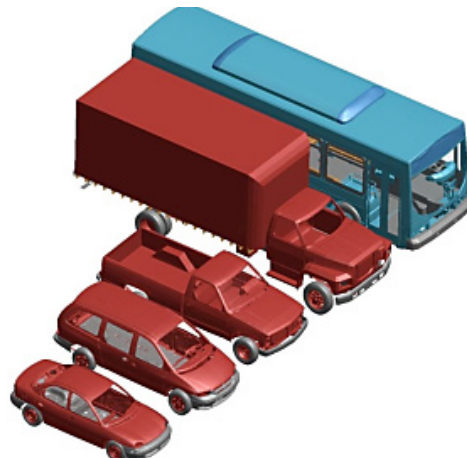
Structural Crashworthiness Evaluation

Using information generated from the literature review of existing standards and accident data, an aggregate FE model of a mass transit bus structure was developed, representing the characteristics of those buses most likely to be involved in fatalities and injuries [2]. After validation, the FE bus model was analyzed (as summarized in reference [3]), using Federal Motor Vehicle Safety Standards (FMVSS) and real world crash scenarios, for:

- Structural response to real-world side, frontal, and rear impact crash scenarios with large trucks, pickups, and compact cars
- Compatibility with large trucks, light trucks, and compact cars with regards to weight, stiffness, and geometry
- Bus rollover and roof-crush response

Figure 2-2

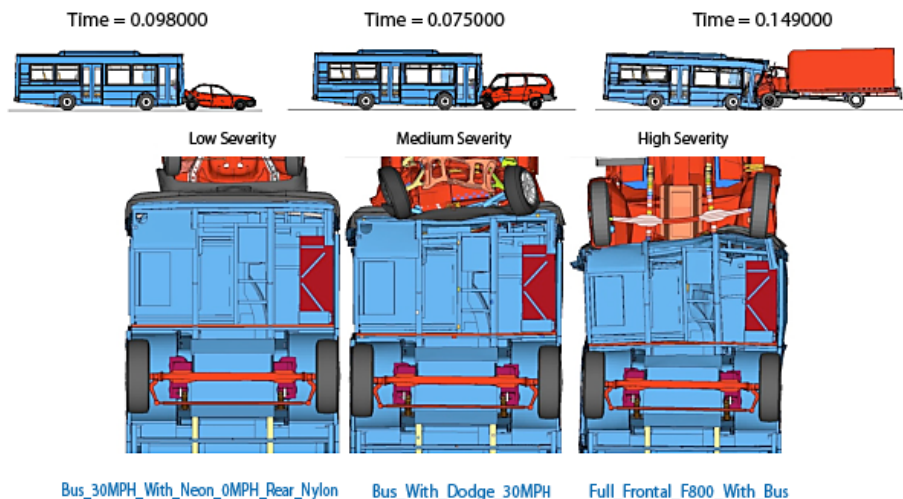
Finite Element model vehicles



Source: Olivares and Yadav [3]

Figure 2-3

Structural deformation for typical low-, mid-, and high-severity crash conditions—frontal impact collisions



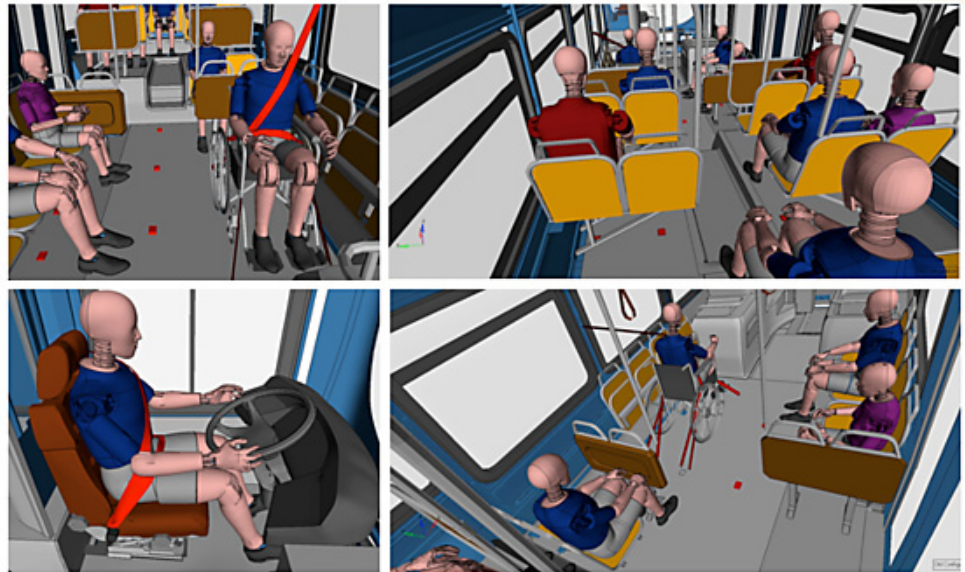
Source: Olivares and Yadav [3]

Interior Crashworthiness Evaluation

Using the crash pulse data derived in the structural virtual testing phase [3], NIAR researchers were able to develop numerical models (Figure 2-4) to evaluate occupant kinematics and biomechanical performance for typical crash scenarios. These evaluations were performed prior to the sled-testing phase to refine the experimental test methodology, hence saving time and resources in the next phase.

Figure 2-4

Finite Element model of mass transit bus interior and occupants



Dynamic Crash Sled Testing

Dynamic testing was carried out in NIAR's Crash Dynamics Lab. Experimental research conducted on occupant crash dynamics was comprehensive. Anthropomorphic test devices ("crash dummies"), ranging in size from 12-month-old infants to males of the 95th percentile, were used in testing. The objectives of the experimental research were to characterize the kinematics and injury mechanism of bus occupants during typical frontal, side, and rear impact conditions. Testing was performed in exhaustive detail; a truncated list of general testing follows. Full testing data are available in references [4] and [5] for:

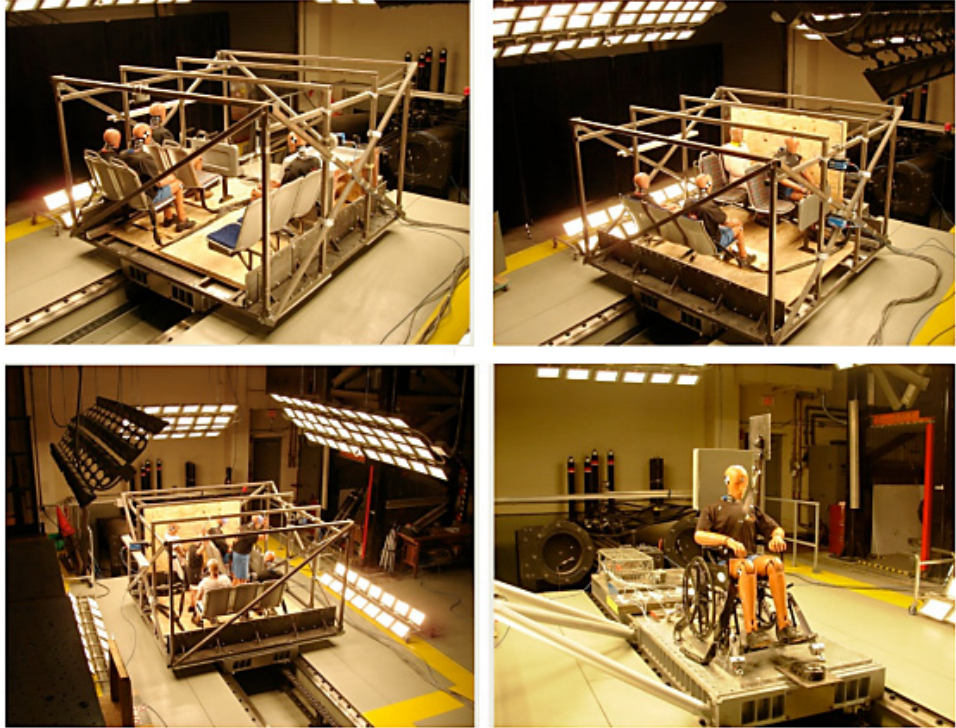
- operator inflatable restraint system design, testing and analysis
- seated occupants tested for frontal, side, and rear impact injury mechanisms
- standing passengers in frontal and side impact testing
- child restraint system interface tested and refined for frontal impact
- wheelchair standards and regulations studied and tested for frontal, side, and rear impact crash scenarios

For each testing phase, analysis was performed on injury mechanisms. Design concepts were developed and tested to improve the level of occupant safety. These

design concepts and concept studies may be used as part of the technical support documents to develop new standards for crashworthiness in the mass transit bus industry.

Figure 2-5

Examples of mass transit bus sled test configurations



SECTION 3

Conclusions and Recommendations

Mass transit buses are a significant part of the national transit vehicle fleet. Improving fatality and injury performance from year to year relies on constant improvements in crashworthiness designs and standards. With five years of research and hundreds of virtual tests and laboratory experiments concluded, NIAR's investigative efforts into bus crashworthiness have yielded recommendations and design concepts for revamping many of the standards and procedures regarding crashworthiness of mass transit buses. These guidelines fall primarily within the parameters of the research objectives, but also included are strong recommendations for improving the current crash database for mass transit buses and integrating numerical modeling into future research and certification procedures. Many of the recommendations are indicative of a need to improve uniformity and standardization, both in construction and certification, across the industry. In the following recommendations, the automotive industry was used as either as a benchmark to compare against or as a source of inspiration.

Structural Recommendations

Structural design for mass transit buses should have two objectives when considering crashworthiness:

- self-protection—the ability of a bus to protect its occupants
- partner-protection—the ability of a bus to minimize injury to the occupants of the vehicle in collision with it

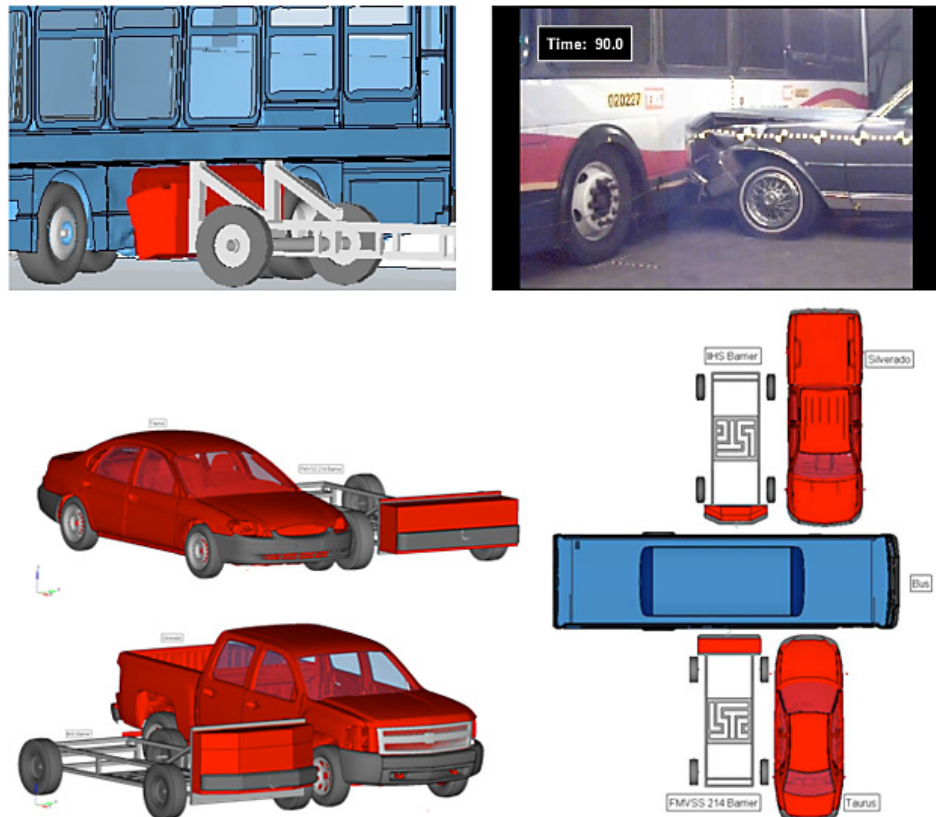
Research conducted on structural analysis had three broad components: impact, rollover, and compatibility, with impact and rollover being studied for self-protection and compatibility being studied for both self-protection and partner-protection. These guidelines are in keeping with the accepted notion that compatibility should be present to the extent that it does not compromise self-protection.

Dynamic Side Impact Evaluation

Due to the high cost associated with full-scale structural testing, validated computer models were used for impact testing. This allowed efficient, inexpensive iterations of typical crash scenarios to be studied. During the validation process, while ensuring that the FE model met all SBPG conditions to be tested, NIAR developed a deformable barrier, based on modifying the standard required in FMVSS 214, to be used in impact testing [2]. In updating and

revising the SBPG, it may be useful to examine the benefits of using such a barrier as that stipulated in FMVSS 214, or perhaps even better, the Insurance Institute for Highway Safety (IIHS) side-impact barrier, which accounts for the substantial change in typical private automobile geometry. Current FMVSS standards are drawn from the 1980s when cars, not SUVs and pickup trucks, were the norm. See Figure 3-1 for the proposed side-impact test configurations.

Figure 3-1
Proposed barrier test
method vs. actual
SBPG test method



Rollover

The mass transit bus simulation model performed well in rollover and roof-crush testing [2]. Though it met and exceeded the static levels required in the SBPG, test results indicate further data in a common theme in mass transit bus design philosophy. Current mass transit bus structures are over-designed. Though the philosophy meets occupant safety standards, it provides a significant opportunity for improving crash compatibility, as well as fuel economy and environmental impact. The use of lighter materials, combined with a change in the structural design philosophy of the mass transit buses, would help to improve the compatibility issues associated with weight. Coupled with further compatibility concept changes, listed below, partner-protection in mass transit bus crash scenarios should improve. Additional rollover testing was performed, in accordance

with European regulation ECE R66, to judge the rollover performance of a fully-occupied mass transit bus equipped with passenger restraint systems. These tests were performed after interior design concepts regarding passenger restraint were formulated. Because of the significant change to the mass coupled to the bus structure, the center of gravity is also substantially changed. If seated passenger restraint systems are introduced in the SBPG—a recommendation not explicitly made in this report—then further validation will be needed in rollover testing.

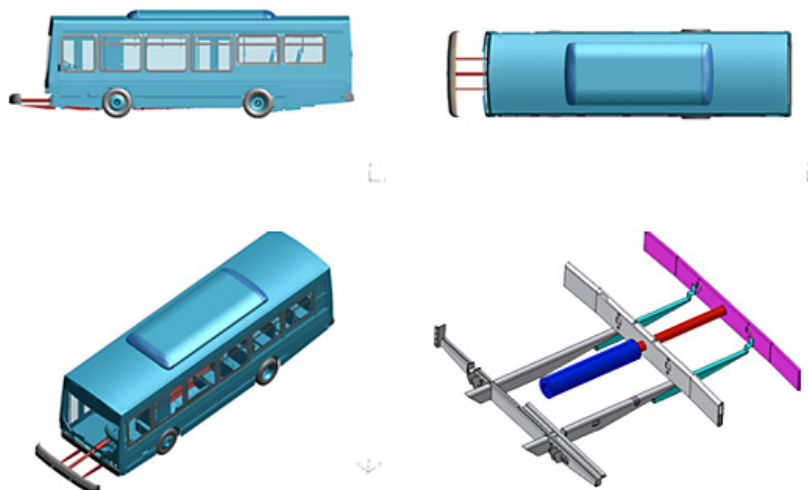
Compatibility

A central focus of the research was the crash compatibility of mass transit buses. Structural compatibility virtual testing was performed with a variety of validated vehicle models, from sedans to heavy trucks, testing specifically for weight, stiffness, and geometric compatibility. In mass transit bus crashes, data taken from 1999–2000 indicate that 43 percent of fatalities were drivers of other vehicles and 13 percent were passengers of other vehicles. There is a clear need for improving partner protection without compromising self-protection in mass transit bus design.

- **Geometry**—Though current bus geometry is compatible with the majority of road vehicles, there are some height mismatches, specifically with large trucks. This can be solved by increasing height values in current design or implementing them in future active bumper systems.
- **Stiffness**—A serious compatibility issue found in the research was vehicle stiffness. In frontal collisions, vehicles with lower stiffness absorbed the bulk of the crash energy. In collisions involving mass transit buses, the bus almost exclusively has higher stiffness. This results in large deformations in partner vehicles and increases the injury potential for their drivers and passengers. The design concept put forth and studied in this research is an active bumper system (Figure 3-2). The system is designed to solve stiffness compatibility issues associated with frontal and rear crashes while also allowing for geometric issues to be addressed as well by increasing/decreasing bumper height as necessary.

Figure 3-2

Energy-absorbing bumper system concept



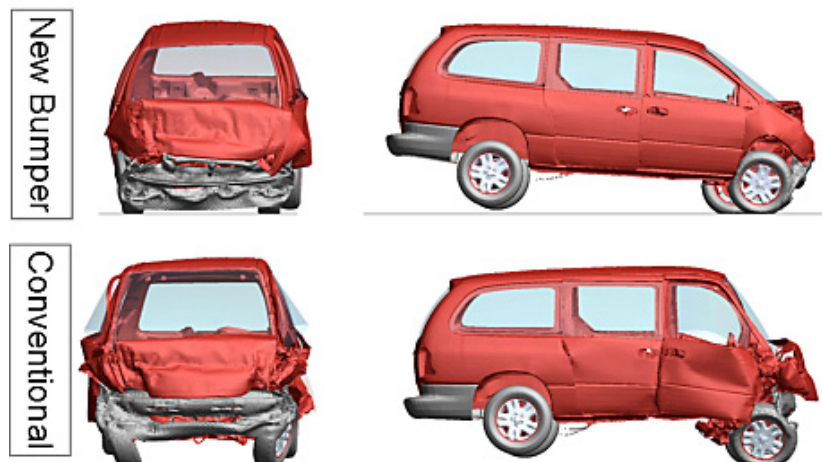
Source: Olivares and Yadav [4]

Smaller vehicles are at a fundamental disadvantage when colliding with a heavier mass transit bus; large deformations cause dangerous intrusions in partner vehicles. To improve vehicle compatibility, both vehicles need to dissipate similar levels of energy. Since mass and impact velocities are fixed parameters, improvements can be achieved by modifying the stiffness and crush distance of the bus structure. Because of current design requirements, specified in SBPG, a new safety concept—the active bumper system—was designed to improve compatibility.

In simulations, the active bumper system was able to reduce deceleration levels and permanent deformations in partner vehicles. However, to improve structural interaction with larger vehicles, it would be necessary to define a bumper system design envelope in the SBPG.

- **Mass**—As noted above, a reduction in weight by introducing a new design philosophy in mass transit buses, one with lighter materials and modern design consideration, would improve bus partner protection as well as improve fuel economy and reduce brake wear.

Figure 3-3
Energy-absorbing bumper system concept, comparison crash deformation



Source: Olivares and Yadav [4]

Interior Recommendations

Mass transit bus interior design has to consider two occupant types: passengers and operators. Operator design is limited to a single person, but passenger protection has numerous configuration variables to account for. NIAR's Crash Dynamics Lab was used to exhaustively test typical crash scenarios with ATDs ranging in size from 12-month-old infants to males in the 95th percentile. These tests were used to validate FE/MB models and design concepts for improving each type of occupant's safety.

Operator Safety

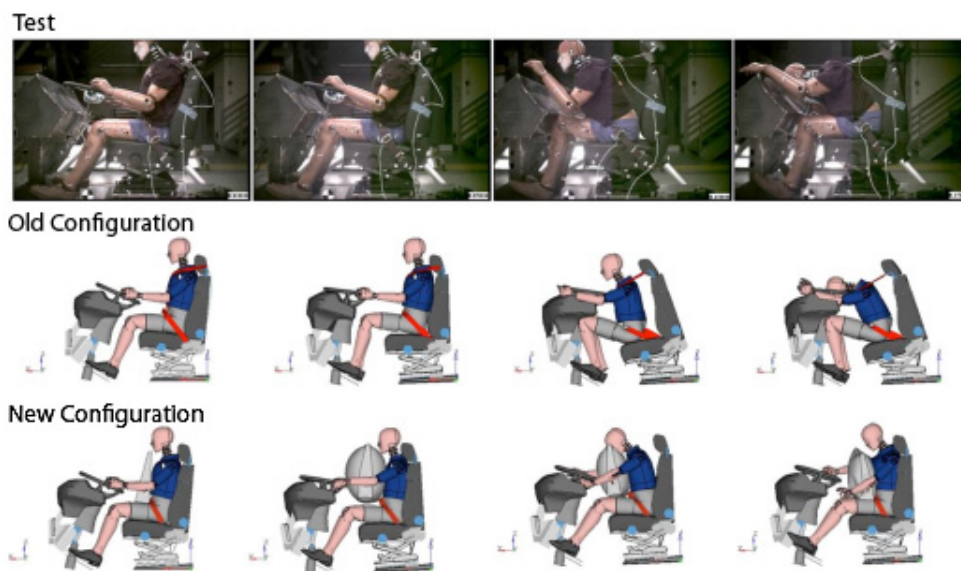
When evaluating operator safety, NIAR first modeled and tested for primary injury mechanisms to the operator using baseline SBPG standards in a simulated

environment under worst-case scenarios. Baseline results, using a two-point lap belt or a three-point shoulder belt for restraint, indicated that head and lower extremity injuries were most common [5]. Design concepts were then created and tested to protect against these injuries and also for chest injury protection. Observations include the following:

- Inflatable restraint systems—research indicates that a two-point inflatable restraint system reduces injury levels below 80 percent of FMVSS 208 limits while reducing weight and increasing operator comfort [5].
- Padding compounds used to bolster the knee impact areas significantly reduce the risk of severe femur injuries. Optimal thickness and stiffness of compound is dependent on cabin configuration.
- Operator seat static strength requirements, as delineated in SBPG 5.4.1.2 to meet FMVSS 207 and 210, should be reevaluated. Data compiled in this research indicate that the loads for which they are designed may be too high and increase the weight and complexity of the seat structure unnecessarily.

To be noted, the inflatable restraint systems tested were highly sensitive in efficacy with regards to the time-to-fire after impact. An effective deployment logic would need to be defined for the restraint system.

Figure 3-4
Simulation and sled test of two-point belt with airbag



Source: Olivares and Yadev [5]

Passenger Safety

The critical occupants of mass transit buses—passengers—were studied according to four main profile types: seated, standing, child, and occupants with reduced mobility. Simulations of frontal, side, and rear impact crashes were studied in typical configurations for seated and standing adult passengers in the 5th through 95th percentiles and children ages 12 months and 3 years. For

most studied cases, occupants suffered neck and head injuries. Primary injury mechanisms included:

- Neck—low seatback height design, insufficient seatback rotational stiffness, and lack of seatback padding or energy-absorbing devices contributed to neck injuries (compression and flexion) in frontal and rear impact conditions (Figure 3-5)
- Head—injuries were caused primarily by passenger-to-passenger contact
- Femur—occupants in side-facing seats suffered femur compression injuries in side-impact conditions

Figure 3-5

Example neck extension and neck flexion injury mechanisms during rear and frontal impact scenarios

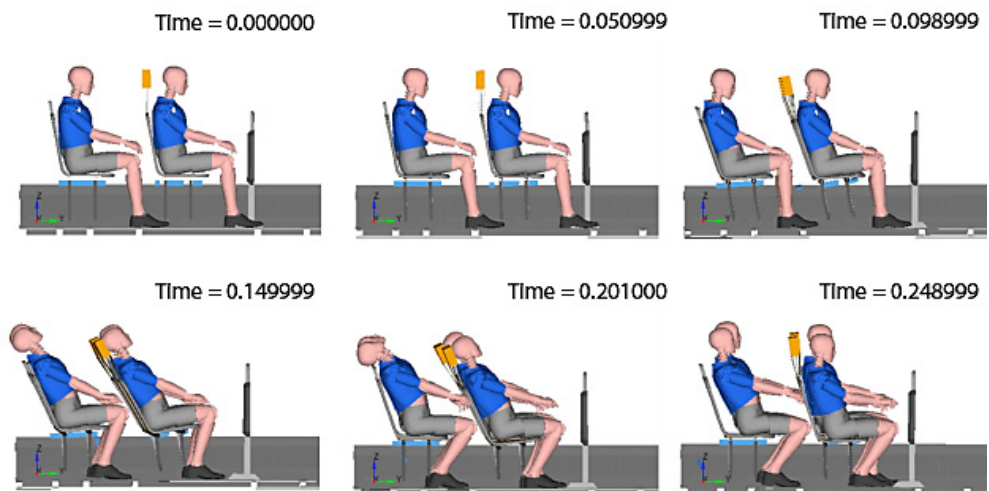


Each of these injury mechanisms was tested for each type of passenger, and design concepts were formulated and tested with validated FE/MB models. The following are observations and suggestions for refining current SBPG and FMVSS guidelines:

- Seated passenger safety
 - Standard seatbacks in mass transit buses are too low to protect against neck injuries. Research indicates high seatbacks and headrests reduce rear impact injuries significantly. Responding to industry concerns that increased seat height would cause a reduction in passenger visibility, NIAR developed a seatback design that provides needed head and neck support while reducing operator-passenger visibility by only 20 percent (Figure 3-6).
 - Introducing offset seat rows could improve the level of protection to occupants during severe side impacts.
 - According to typical crash scenarios and conditions, with proper compartmentalization design methods, the use of passenger restraint systems is not required to meet injury criteria defined in FMVSS standards.

Figure 3-6

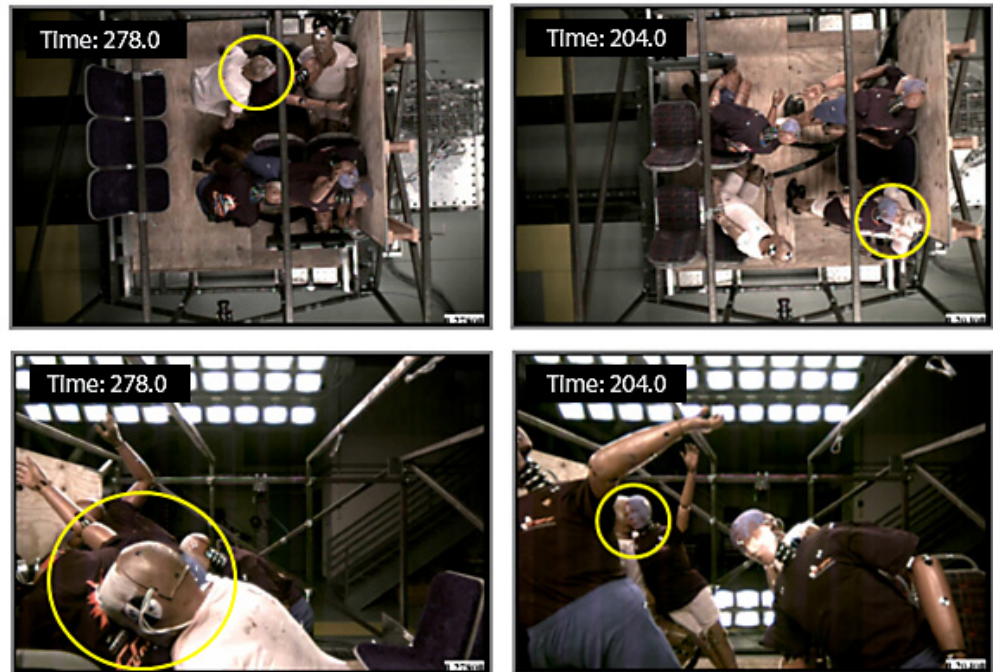
Conventional seat layout vs. proposed high seatback seat layout—rear impact scenario



- Standing passenger safety

- Side-facing seats are strongly recommended against, for the protection of both the seated passengers in them and standing passengers (Figure 3.7). Side-facing seats provide direct exposure to standing occupants from those occupying the seats and allow more space to build up impact speeds.
- Similarly, it is strongly recommended to remove rear center (aisle) seats, removing the danger to standing occupants from being struck by those seated in them during a crash.

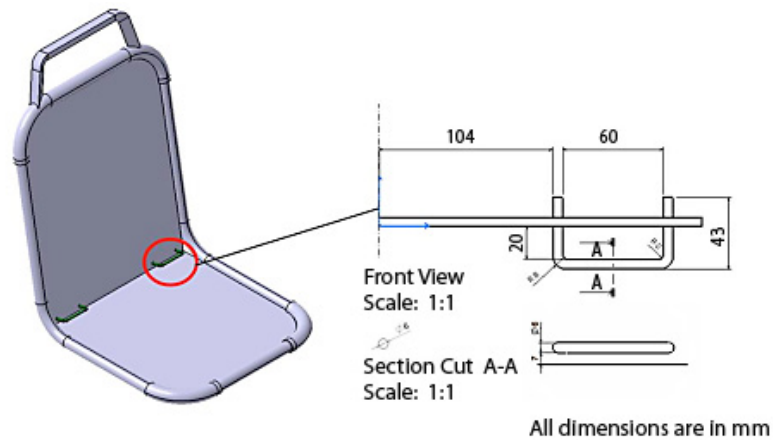
Figure 3-7
*Typical injury
 mechanisms for
 standing passengers*



- Child safety
 - Currently, in mass transit buses, there is a lack of child-specific injury protection. A feasibility study was performed to adapt Automotive Child Restraint Systems (CRS) for use in transit buses. Research indicates that the Lower Anchors and Tethers for Children (LATCH) system, built to FMVSS 213 and 225 standards and compatible with all child car seats using the LATCH design, provides an increased level of safety for child occupants. While the LATCH system allows for a three-point connection, only the two anchor points are required for use in buses, for several reasons:
 - o The introduction of a two-point CRS in buses does not pose a risk of injury to adult passengers, as shown on the dynamic sled-test results.
 - o Industry concerns are met to minimize modification made to mass transit bus interiors.
 - o It reduces time to secure the CRS.
 - o The upper tether attachment is not deemed essential to safety at the likely speeds in a typical crash scenario (Figure 3-8).

Figure 3-8

Proposed
LATCH-style child
restraint system



Source: Olivares and Amesar [6]

- Safety of occupants with reduced mobility
 - Wheelchair restraint systems were tested with numerical models and physical sled-testing. Current safety standards provide a good level of protection during typical crash scenarios and do not represent an injury risk to other occupants. Additional safety for rear impacts or aft-facing configurations can be improved with the introduction of head rests to prevent neck injuries (Figure 3-9).

Figure 3-9

Modified headrest support for rear impacts



General Industry Recommendations

In addition to structural and interior safety concepts, several general industry recommendations were formulated as a result of NIAR's research. These recommendations are intended to facilitate future research programs and promote efficient use of industry resources in certification and standardization processes.

National Mass Transit Bus Crash Reporting System/Database

In the literature review phase of NIAR's study, at the outset of the research, difficulties were encountered in industry reporting of mass transit bus crash incidents. Instead of a federally-administered, central crash database, various local municipal and state-run databases are maintained, often with very different degrees of detail. It is the recommendation of this study that the mass transit bus industry adopt a database reporting system similar to the Fatality Analysis Reporting System (FARS) or the National Automotive Sampling System (NASS) maintained by NHTSA for the automotive industry. If implemented, future research will have an advantage of comprehensive annual, national statistics for mass transit bus crash injuries and fatalities for occupants, partner-vehicles and their occupants, and pedestrian traffic. This will help future researchers better characterize typical crash scenarios and lead to better recommendations for improved crashworthiness.

The mass transit bus industry has another burgeoning advantage. With an increase in the number of closed-circuit camera units installed in mass transit

buses, a repository for the footage captured during crash involvements could give the industry an unprecedented edge in characterizing typical crash scenarios.

Virtual Testing

One of the most important areas in NIAR's approach to crashworthiness research is numerical modeling. When used in conjunction with experimental static and dynamic testing, numerical modeling allows for an efficient, iterative, cost-effective method to evaluate the crashworthiness behavior of mass transit buses. It is the strong recommendation of this study that the mass transit bus industry adopt these techniques for testing and certification in an effort to modernize the industry and improve vehicle crashworthiness.

A change in structural and interior design philosophy need not be a daunting undertaking. With judicious use of validated mathematical models, changing from an over-engineered bus design to a modernized design with lightweight materials and structural components can be achieved using a fraction of the resources it would take using only traditional experimental techniques, building and testing full-scale models.

SECTION

4

Future Research

The following areas should be addressed in future research projects:

- Evaluate and improve the safety of standing passengers with active human body models.
- Develop design guidelines for mass transit bus interiors.
- Develop virtual design and certification methods for the mass transit industry.
- Summarize the synergies between the crashworthiness research for light rail vehicles and mass transit buses.

GLOSSARY

ATD	Anthropomorphic Test Device—“crash dummy”
CRS	Child Restraint System
ECE	Economic Commission for Europe
FARS	Fatality Analysis Reporting System
FE	Finite Element—the use of finite element models in simulating crash scenarios
FMVSS	Federal Motor Vehicle Safety Standards
FTA	Federal Transit Administration
HIC	Head Injury Criteria—the measure of likelihood of a head injury resulting from impact
LATCH	Low Anchors and Tethers for Children
MB	Multibody—the use of multibody models in simulating crash scenarios
NASS	National Automotive Sampling System
NHTSA	National Highway Traffic Safety Administration
NIAR	National Institute for Aviation Research
SBPG	Standard Bus Procurement Guidelines
TSF	Transport Safety Facts

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