



White Paper

“Compartmentalization and the Motorcoach”

By: SafeGuard, a Division of IMMI
April 9, 2009

Table of Contents

Introduction.....	3
Compartmentalization in School Buses.....	3
Lap-Shoulder Belts on a Compartmentalized School Bus Seat.....	5
SafeGuard Solution: SmartFrame™ Technology.....	6
Compartmentalization in Motorcoaches.....	6
Conclusion.....	9

Introduction

Compartmentalization is a concept that has been used for more than 30 years in school transportation to provide protection in frontal or rear impact crashes for unbelted passengers. Required by federal regulation in school buses, compartmentalization provides protection for unbelted occupants through the use of high-back padded seats, which are designed to yield as they are impacted. Passengers impact the seat in front of them, and the seat absorbs their crash energy.

Testing, as well as real world experience, shows that compartmentalization offers protection in frontal and rear crashes but virtually no protection in rollovers or side impacts. Research by the National Highway Traffic Safety Administration ([NHTSA](#)) indicates that lap-shoulder belts, in every vehicle in which they have ever been introduced, reduce injuries and fatalities by approximately 45 percent. Seat belts provide the best protection in any moving vehicle.

Compartmentalization in School Buses

When Congress called upon NHTSA in the early 1970s to improve school bus safety, one critical area that NHTSA had to address was occupant protection. School bus seats and interiors were not friendly to children impacting them in crashes. This resulted in injuries and fatalities that could perhaps have been avoided.

At that time, seat belts had been required in U.S. passenger cars for approximately 10 years, beginning with front seat lap belts in 1963, and then lap-shoulder belts in front seats in 1968. Given the general population was not yet accepting seat belt use in passenger cars, it was thought to be unlikely for children to use restraints in school buses. Therefore, NHTSA sought a means of passive protection for children on buses.

The concept of compartmentalization became NHTSA's solution for providing passive protection on school buses. Compartmentalization was formalized in 1974 as a Federal Motor Vehicle Safety Standard (FMVSS), which would go into effect on all new school buses built after April 1, 1977. Unchanged in concept for more than 30 years, compartmentalization has proven itself as a successful means to protect children on school buses in many types of frontal and rear crashes.

Compartmentalization is defined in [FMVSS 222](#) by design requirements and details such as seat spacing. Performance standards are established in two primary areas. First, the standard requires the seatback to absorb an occupant's energy in a crash. Second, the standard requires the seat to provide impact protection to the occupant when he contacts the seatback during a crash. To validate seats meet these requirements, NHTSA calls for seats to be tested on a bus body structure.

To prove the seat's capability to absorb an occupant's crash energy, forward and rear deflection tests are performed. One load bar is placed at a height representing the impact area for the occupant's knees. A second load bar exerting a greater force is placed at a height representing the impact area for the head, neck and shoulders. During testing, the upper load bar causes the seatback to yield, and the load is measured over the distance the seatback moves forward. Load data is placed on a curve with bounds (minimum energy absorption) established by FMVSS 222.

The area under the curve represents the energy that the seatback absorbs. A rearward deflection test is similar. See Fig. 1 and Fig. 2.

Figure 1 – NHTSA FMVSS 222 force/deflection chart

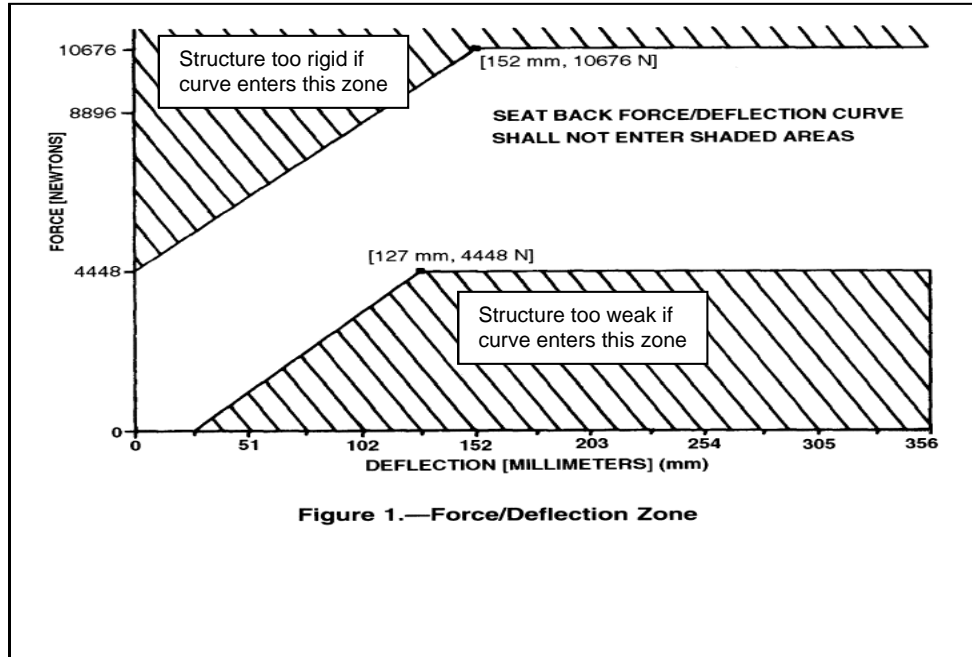
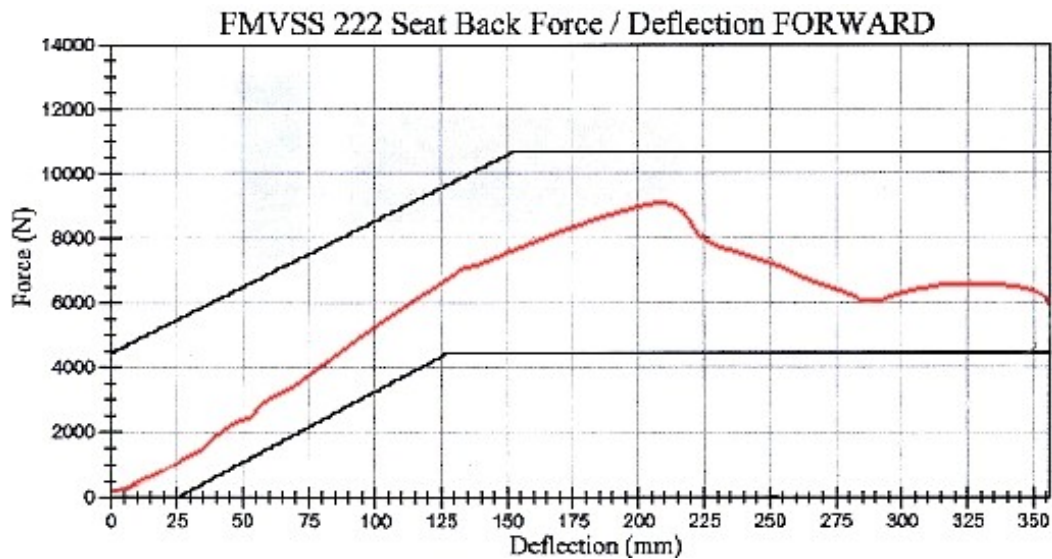


Figure 2—SafeGuard Premier load data on FMVSS 222 force/deflection chart, indicating passing results



A seat designed with an overly rigid structure will result in a curve that goes above the FMVSS 222 bounds. In application, this type seat resembles an almost unyielding surface that an unbelted occupant would accelerate into during a frontal collision, potentially resulting in injuries or a fatality.

A seat with a structure that is too weak will result in a curve that goes below the lower FMVSS 222 bounds. During a frontal collision, this seatback would easily fold over by the force of the unbelted occupant, permitting him to continue his forward motion and move out of the compartment defined by the seat spacing. This too may result in injuries or a fatality as the occupant could impact other occupants or hard points within the motorcoach interior.

The second main area of testing represents the ability of the seat to provide impact protection to occupants when they contact the seatback during a crash. During this test, two spherical forms (one representing the head and one representing the knee) are accelerated into different points on the seatback. Several different performance criteria must be met for the seat to be approved. A seat would fail this test if the forms impact hard points that could cause severe injuries or even fatalities when an occupant makes contact.

Lap-Shoulder Belts on a Compartmentalized School Bus Seat

Testing, as well as real world experience, shows that compartmentalization offers protection in many types of frontal and rear crashes if children are properly seated, but offers virtually no protection in rollovers or side impacts. The 1999 National Transportation Safety Board (NTSB) Special Investigation Report concludes: “Current compartmentalization is incomplete in that it does not protect school bus passengers during lateral impacts with vehicles of large mass and in rollovers, because in such accidents, passengers do not always remain completely within the seating compartment.”

Although incomplete, compartmentalization is an important element of bus passenger protection, since drivers typically cannot ensure every passenger remains belted for the duration of every ride. While it is a well-documented fact that seat belts provide the [best protection](#) in any moving vehicle, the addition of lap-shoulder belt restraints introduces a dilemma to compartmentalization.

Seats used on school buses must comply with FMVSS 222. Since the seatback is designed to yield forward when an occupant impacts it, a shoulder belt may pull the seatback forward and “steal” compartmentalization from the unbelted occupant seated behind. If the seatback were made more rigid to resist yield, the application of a shoulder belt load would mean the seatback could cause injury to the unbelted occupant seated behind.

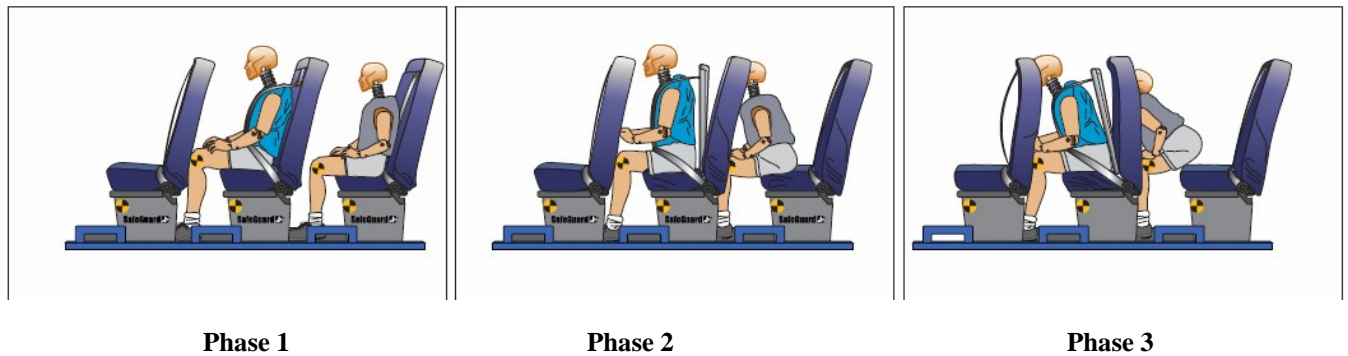
SafeGuard Solution: SmartFrame™ Technology

The solution to this dilemma would be a compartmentalized seat combined with lap-shoulder belts that don't compromise compartmentalization. One solution is offered by SafeGuard with its SmartFrame technology. Bus seats utilizing SmartFrame technology are found in both the school transportation market and in the motorcoach market.

Here's how SmartFrame works: SafeGuard bus seats are made with two independent structures. The inner structure provides lap-shoulder belts and absorbs crash energy for the belted passenger. The outer seatback structure remains upright and then yields as it cushions and absorbs the energy of anyone in the seat behind who isn't wearing a seat belt.

This is demonstrated below. In Phase 1 (pre-crash), a belted occupant sits in the middle row and an unbelted occupant is seated behind. In Phase 2, the belted occupant in the middle row moves forward with the crash, causing the SmartFrame to yield forward in a controlled fashion away from the outer seatback, which remains in its original position. In Phase 3, the unbelted occupant in the last row impacts the seatback, causing it to yield forward and provide full compartmentalization protection.

School Bus Seat Crash Test



Compartmentalization in Motorcoaches

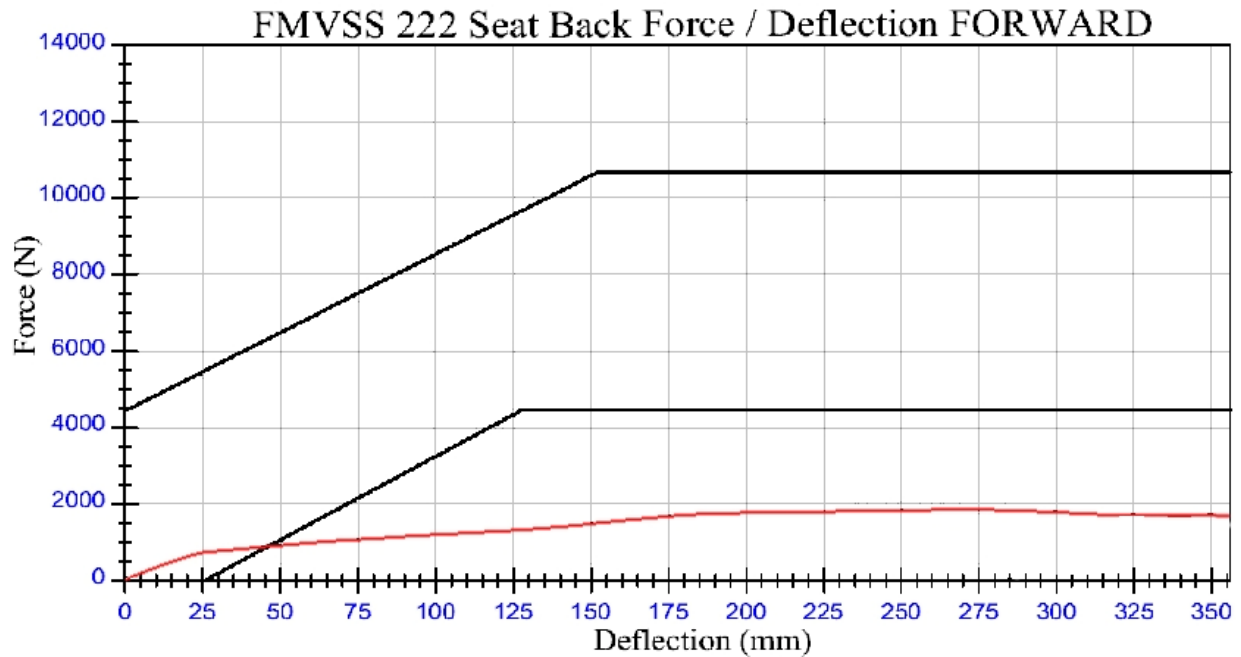
For many years, the motorcoach industry has believed their vehicles provide compartmentalization protection. At a joint hearing of NHTSA and Transport Canada on April 30, 2002, members of the industry testified that there was no need for adding restraints since motorcoaches provided safety by compartmentalization. However, the definition of compartmentalization becomes problematic. Within the motorcoach industry, the definition has been limited to two areas: spacing seats within a reasonable distance of each other and keeping seatbacks high enough that the head of an adult occupant would remain below the top of the seat.

Within the motorcoach industry, the definition of compartmentalization has not included design requirements, performance standards and details such as maximum seat spacing, which are all clearly defined by FMVSS 222. Motorcoach seats have not been developed to properly absorb the energy of unbelted occupants seated behind. Furthermore, motorcoach seat manufacturers

have not previously established design specifications that require seatback surfaces to prevent contact injuries.

IMMI/SafeGuard and the Center for Advanced Product Evaluation (CAPE) have conducted performance tests on several current motorcoach seats, both with and without restraints. FMVSS 222 forward deflection tests were performed on these seats. The load deflection curves that were generated (**Fig. 3**) were significantly below the lower bounds of the FMVSS 222 requirements, indicating that the seatback had insufficient structure and ability to absorb energy. Similarly, the hard plastic surfaces on these seatbacks are incapable of meeting any of the impact test requirements and therefore could result in contact injuries.

Figure 3 – Current motorcoach seat load deflection curve, indicating the seat structure is too weak to pass FMVSS 222



In the side-by-side comparison shown in **Images 1 and 2** below, all test dummies are unbelted. Both screen captures demonstrate what happens in a 30 mph frontal collision. On the left are test dummies in current non-belted seats, and on the right are dummies in Premier seats. Note that passengers riding in the Premier receive the full benefit of compartmentalization.



Image 1: Current seat, all unbelted



Image 2: Premier, all unbelted

The dynamic sled tests were run at CAPE with a deceleration pulse representative of the pulse that NHTSA produced when performing their motorcoach barrier crash test in December 2007. In CAPE testing, when the unbelted occupant impacted the seatback of a current unbelted seat, there was a quick, extreme yielding of the seatback in front, causing the occupant to launch up and forward.

A seat designed for true FMVSS 222 compartmentalization can provide real passive protection for an unbelted occupant in a motorcoach. The SafeGuard Premier motorcoach seat does this, utilizing the same SmartFrame technology discussed earlier for school buses. FMVSS 222 load-deflection curve requirements are met (**Fig. 2**). In dynamic sled tests, unbelted occupants stayed in the compartment, regardless if the occupant seated ahead was belted or unbelted.

In the side-by-side comparison below, **Images 3 and 4** clearly demonstrate the benefits of SmartFrame for protecting belted and unbelted passengers. In both of these screen captures, the front row of passengers is belted, and the back row is unbelted. Conventional three-point seating is at the left, and Premier is tested at the right. Under the same testing conditions, notice the dramatic difference in passenger protection. Also notice the separation of the inner SmartFrame on the Premier seat. At this point in the crash, the gap between the inner and outer structure has been nearly closed back up by the impact of the unbelted passenger from behind.



Belted

Unbelted

Image 3: Current seat, belted and unbelted



Belted

Unbelted

Image 4: Premier, belted and unbelted

Conclusion

Testing, as well as real world experience, shows that compartmentalization offers protection in many types of frontal and rear crashes, but virtually no protection in rollovers or side impacts.

Lap-shoulder belts provide the best protection in any moving vehicle.

Compartmentalization can be an effective form of passive protection for an unbelted occupant in many frontal or rear collisions. FMVSS 222 was established for school buses to assure that compartmentalization protection existed in every school bus seating position. Motorcoaches are not required to meet FMVSS 222, and current design motorcoach seats do not provide true compartmentalization protection. Premier is the only motorcoach seat now available that offers true compartmentalization protection with the added protection benefit of adjustable lap-shoulder belts to protect the entire ridership population.

For more information about compartmentalization and SafeGuard SmartFrame, visit safeguardseat.com or contact IMMI at 317-896-9531.