

Development of a dynamic testing procedure to assess crashworthiness of the rear patient compartment of ambulance vehicles

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ABSTRACT

Ambulances have different performance needs and structural design compared to standard passenger vehicles. Also occupants in the ambulance rear patient compartment maybe side facing, rear facing or recumbent. There is also no USA dynamic safety standard for testing the ambulance patient compartment occupant or equipment restraint systems. This study describes an accelerator sled test conducted of an ambulance rear cabin environment which demonstrates some optimal restraint practices for pediatric patients and also the interaction between the different occupants and the need for effective restraint systems. The goal of this study was to analyze occupant kinematics and forces generated in a model of an ambulance crash, and to test injury-mitigating countermeasures for both pediatric and adult occupants. The major limitations of this study relate to the deficiencies in the data to define a valid crash test pulse for this ambulance rear cabin vehicle component, in addition to the generalizability of the specific vehicle components tested in this study.

The ambulance transport environment includes predictable and preventable occupant risks. Failure to use current methods of occupant protection and equipment tie-down can result in catastrophic outcomes to all occupants. Occupant kinematics and forces demonstrated that unsecured occupants are a risk to both themselves and also to other occupants. The system used for attaching the CRS to the gurney demonstrated effective restraint for the child occupant. Standards for ambulance occupant safety need to be developed.

INTRODUCTION

In contrast to comprehensive research and development focus on occupant protection in passenger vehicles by the automotive safety industry, the occupant safety of ambulance vehicles, specifically the patient compartment, has not yet been addressed by the automotive safety paradigm. There has been very limited research on the biomechanics of occupant safety in the ambulance environment ^{1,2}. Although the data are limited, emergency medical service vehicles in the United States have high crash and fatality rates per mile traveled ^{3,4,5}. There are estimated 50 fatalities per year, with a quarter of these fatalities being occupants in the ambulance vehicle ⁶. The injury rates are estimated to be 60 fold higher than the fatality rates. Ambulance vehicles are unique vehicles in that they are constructed from a standard truck chassis, with an after market custom box secured as the patient compartment. There are a number of different types of vehicles, Type I and Type III being modified trucks and Type II, a modified van. Vehicles of the truck type tested in this test have a gross vehicle weight of approximately 14,050 pounds. Dynamic safety standards for testing occupant or equipment restraint systems in the ambulance patient compartment are lacking in the United States. The only formal standards are purchase specifications, not performance specifications, (the 'KKK-D' Star of Life specifications ⁷). A consensus panel assembled by the Emergency Medical Services for Children and the National Highway Traffic Safety administration recently developed preliminary guidelines for safe ambulance transport of children ⁸. Australia has had longstanding safety standards for the air transport of patients and crew⁹, however it was not until 1999 that Australia ¹⁰ and Europe¹¹ have each developed some safety standards for occupant protection for ground ambulance vehicles. The objective of this study is to conduct and analyze sled tests of occupant kinematics and forces generated under crash circumstances in the ambulance patient compartment, and also to test some injury mitigating countermeasures for adult occupants and a pediatric simulated patient.

TESTING METHODS

Test Setup:

One frontal impact test of the rear patient compartment of a 1999 ambulance box (figure 1) manufactured by a major ambulance manufacturer was conducted. The primary purpose of the sled test was an industry initiative to analyze the mounting mechanism of the rear patient compartment to the chassis and also to assess a new gurney and gurney mounting system. The research teams involvement in this test was a secondary purpose and a largely fortuitous opportunity. Overall this test was performed to evaluate the performance of :

- The attachment hardware for mounting this ambulance body to a vehicle chassis
- A newly developed gurney and gurney hold downs
- A newly designed passive crew restraint on the front end of the right-side squad bench
- The attachment of a representative child restraint to the gurney
- The performance (HIC and Chest G's) of a child Hybrid III ATD in an FMVSS 213 approved child safety seat secured onto the gurney.
- Evaluation of kinematics of 2 uninstrumented 95%ile ATDs, and kinematics and electronic data of a Side Impact Dummy (SID)

Inside the box were four ATDs. Their seating positions and method of restraint was as follows:

- The three year-old Hybrid-III (H-III) child ATD was positioned in a standard passenger vehicle convertible child restraint seat (CRS) with a standard five-point harness. This safety seat was attached to the stretcher with 2 standard patient restraint belts. (Figure 2)
- The 50th percentile male Side Impact Dummy (SID) was unrestrained and seated at the forward end of the squad bench equipped with the passive restraint device. (Figure 3)
- A 95th percentile male Hybrid-II ATD (un-instrumented) was restrained in the rear most position of the squad bench, a side facing position and was restrained with the lap belt normally fitted to the vehicle (Figure 3)
- A 95th percentile male Hybrid-II (un-instrumented) was positioned in the rear-facing attendant's seat (Captains Chair) and was restrained with the lap belt normally fitted to the vehicle.

All of the ATDs were seated in the upright position pre-test. The SID and three year-old H-III child ATD were instrumented to allow evaluation of their performance relative to known injury assessment values.. Data were acquired in accordance with SAE J211. In addition eight high-speed film cameras were used to record the test. All cameras were run at 1000 frames per second.

This test was conducted on a HYGIE test sled which generated the required acceleration pulse. There was no crash test data available to determine the exact pulse experienced in a crash of an ambulance. Without any information to make an informed decision to change the pulse, the same pulse that was used in a similar test in 1991 for the test was used in this study. Both the 1999 and 1991 tests the target sled pulse was 26 G and 30 mph.

RESULTS

Ambulance Box Parameters:

There was separation of the ambulance box from the sled prior to 35 milliseconds. Due to the separation of the sled and the box, some data channels were compromised, which prevented the complete evaluation of the test data. The resultant peak acceleration of the sled was 34.3 G's. The peak velocity for the sled was 34.34 mph. The overshoot was due to the effect of losing the mass of the ambulance box when it separated from the sled.

The lower ambulance box acceleration appears to have reached approximately 20 G's during the test. The peak velocity achieved by box, prior to loss of data, was less than 21 mph. Sled accelerations at the point it was apparent that the sled and the ambulance box were no longer coupled was little more than 20 G's, and its velocity was approximately 10 mph.

Six of the 10 coupling bolts, securing the ambulance box to the sled/chassis, fractured on impact, allowing this separation of the ambulance box and sled/chassis to occur.

Occupant Kinematics:

After impact, the ATDs that were restrained remained in approximately their pre-test positions. The unrestrained SID impacted and fragmented the passive restraint device. This device failed to restrain the SID, which then became airborne and impacted the forward bulkhead cabinet with its head. The HIC was projected to be greater than 1000, due to the high velocity impact of head into a rigid surface. The SID's final rest position was lying forward of its initial position, near the top of the stretcher, with the head within the structure of the stretcher (figure 4). The H-III child ATD was in approximately the same position pre and post-test and demonstrated minimal motion during crash event. The HIC recorded from the restrained child ATD was 171. The side facing ATD remained restrained, however kinematic analysis demonstrated that the upper body rotated laterally 90 degrees to the horizontal position with some excursion of the pelvis. The rear facing ATD demonstrated minimal motion, and appeared fully supported by the seat back throughout the crash event. This occupant appears to be in approximately the same position pre and post-test, though the ATD is shifted slightly forward

Occupant Protection:

Only two of the four ATDs used in this testing were instrumented to allow ATD response parameters to be recorded. Of the standard calculated values used in accessing test result, only HIC for the child ATD was available. This was calculated using a 36 milliseconds maximum duration.

With regard to the SID, there was data loss due to disruption of data channels upon impact, however the high head acceleration values measured are of great concern. The SID crashed through the passive restraint on the forward end of the crew bench and impacted the front bulkhead cabinet. The head accelerations for the SID prior to head impact were very low indicative of a lack of coupling between the dummy and the vehicle, as expected with no seat belt used. The electronic data in conjunction with the SID's kinematics suggest that this occupant would likely have sustained a high severity injury to both the head and the lower spine and a major soft tissue injury to the liver and other abdominal structures.

For the H-III child ATD it is apparent that the child was well restrained during the crash. The head and chest resultant accelerations were 42 and 29 G's, respectively. The HIC was reported to be 171 which is well below the 1000 used as a threshold by FMVSS 213 to evaluate child restraints, and is also below even the most conservative proffered thresholds.

Child Restraint Performance:

The child restraint system appeared to perform well in this test. It remained well secured to the stretcher throughout the impact. Post-test inspection of the CRS revealed that the shell had marks consistent with belt loading on the upper child harness slots and the rear-facing belt path slots. There was minor bunching of the child restraint harness at the latch plates. Neither of the belts used to restrain the CRS to the cot showed any significant signs of loading. All of these facts are consistent with the expected loading in this test. There were no signs that the CRS was nearing the limits of its ability to protect an occupant, nor was there any evidence of substantial occupant motion during the test.

DISCUSSION

It does remain somewhat ironic that the very vehicle that is there to rescue occupants from an automotive crash, is in itself not a vehicle that meets any substantive crashworthiness or occupant safety standards. This study is a preliminary step in a more comprehensive program to address the crashworthiness of ambulance vehicles in the United States.

Clearly this study highlights the need for more research and development in this area. Specifically, refinement of the testing procedure to reflect more accurately real world crash conditions, and also modification of the data collection system so that data are not lost during events that occur during impact, should be performed.

The limitations of this study included a number of issues that relate to the generalizability of the results:

- The lost data limited the detail of the analysis that could be performed

- The vehicle patient compartment used in this study may not have been representative of the fleet of ambulance vehicles on the road.
- The stretcher and its attachment system may not have been representative of the typical equipment used in the field
- There was no specific crash pulse or accelerator sled pin designed specifically for this vehicle impact environment
- There are limited data on the crash configurations for ambulance vehicles to determine which are the most hazardous for injury
- There was minimal medical equipment positioned in the rear cabin and given the potential for damage to photographic and other test equipment no attempt was made to simulate the impact this equipment would have on occupant safety.
- The attachment system for the patient compartment to the chassis may not have representative of the fleet of ambulance vehicles on the road

It may be that an augmentation of the occupant safety of these may include an energy absorbing structure to be included in the method of attaching the patient compartment box to the chassis. The development of accurate and valid crash test pulses based on full vehicle crash tests of vehicles representative of the fleet should be addressed. These pulses are necessary in order for validated sled testing to be conducted of the rear patient compartment so as to advance the understanding of safety initiatives required for these unique vehicles. There is also a need to collect the information on crash types that are associated with injury and fatality, including occupant and equipment position and restraint systems in use, so that the appropriate testing schedules can be conducted reflecting real world practice.

CONCLUSION

The ambulance transport environment while hazardous includes predictable and preventable occupant risks. Failure to use the restraint systems currently fitted to vehicles creates risk for serious injury to both the occupant who is not restrained and can also create hazards for other restrained or unrestrained occupants. Current methods of passive occupant protection can fail catastrophically. The belting system used for securing the CRS to the gurney demonstrated effective restraint for the child occupant. The restraint practices for these high-risk vehicles need to be reviewed and effective systems need to be designed and appropriately tested under impact conditions. The absence of validated crash pulses and testing standards for these modified vehicles must be addressed. There is a role for the reevaluating of the design of ambulance vehicles with a cross disciplinary team including EMS providers, automotive engineers, and public health researchers. Standards for ambulance vehicle occupant safety need to be developed.

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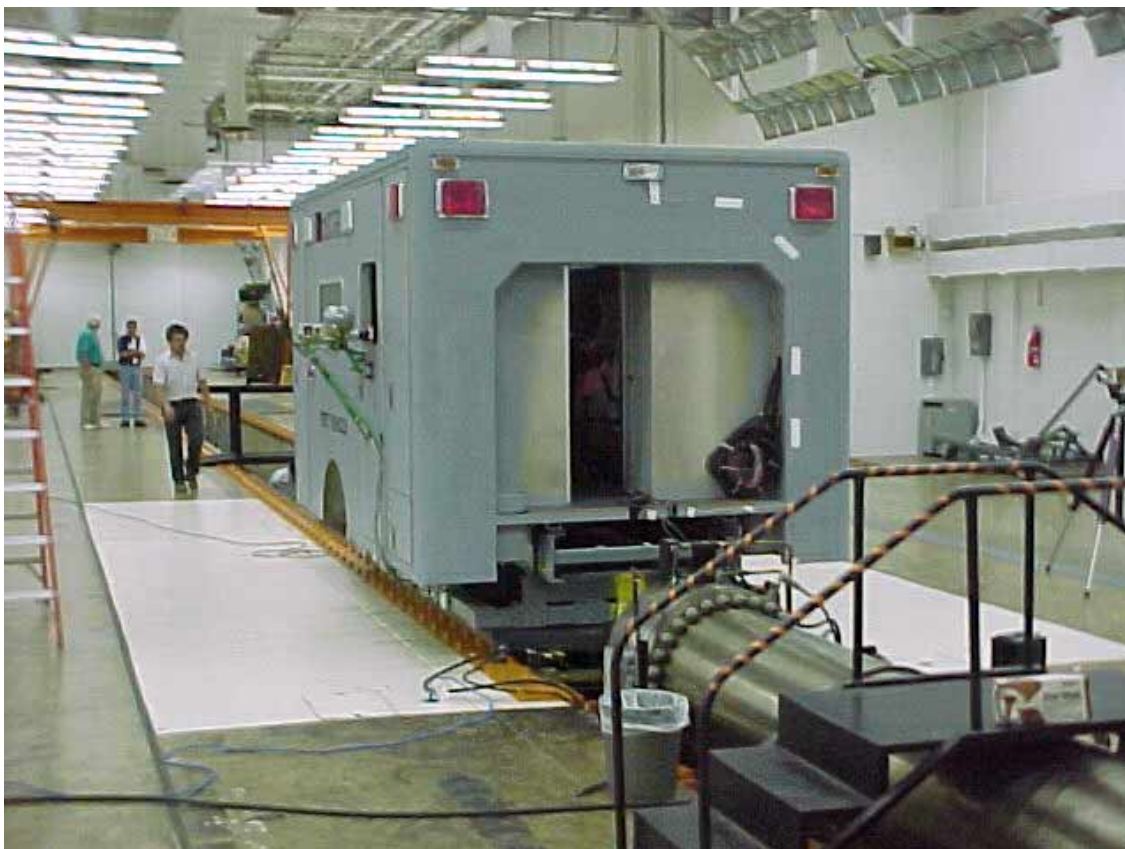


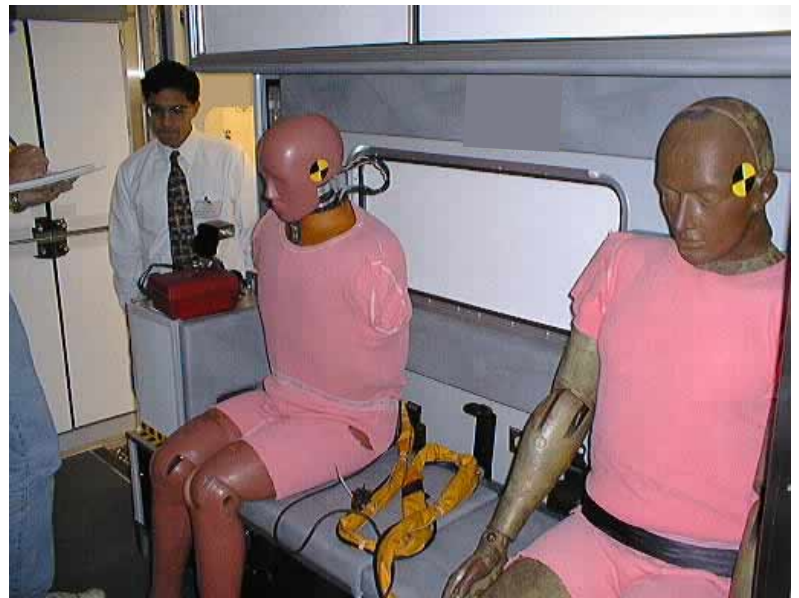
Figure 1. Ambulance rear patient compartment on HYGE accelerator rig



Figure 2. CRS and Child ATD Installed on stretcher



a.



b.

Figure 3a and b. Interior of the ambulance box and the ATDs on the Squad Bench, Captains Chair and gurney

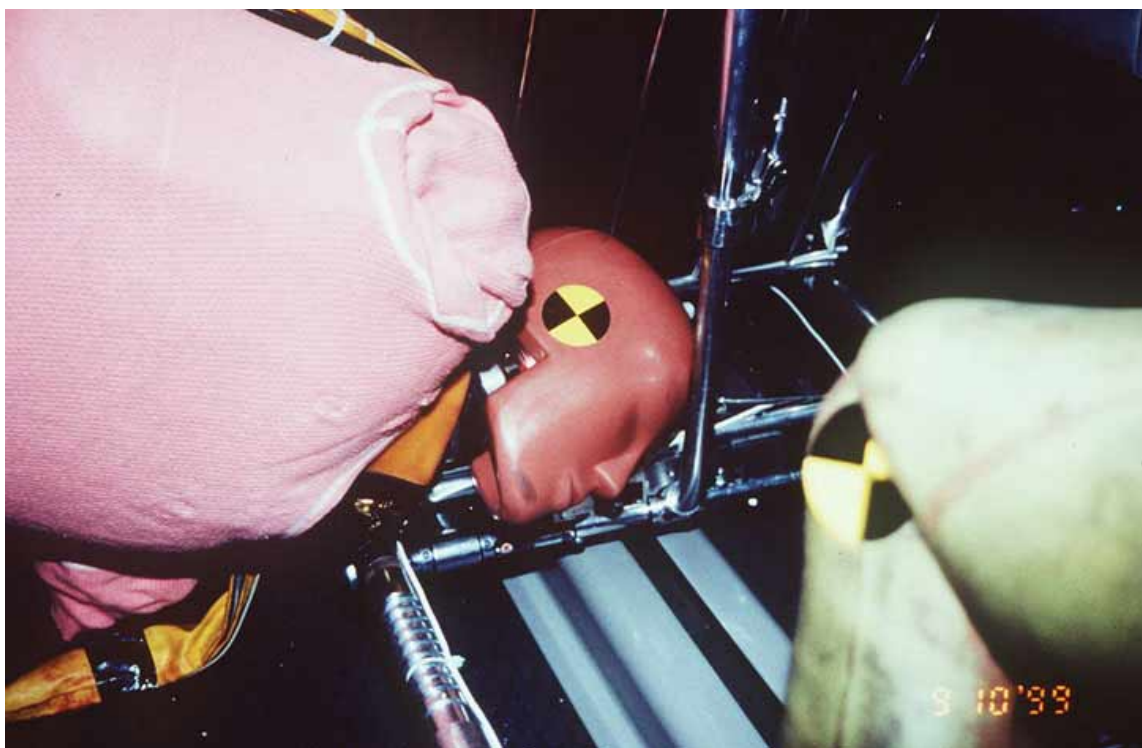


Fig. 4 Post crash test configuration of unrestrained SID