

Ambulance Vehicle Crashworthiness and Passive Safety Design: A Comparative Evaluation

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ABSTRACT

Ambulances are largely exempt from crashworthiness and occupant protection passive safety design standards in the USA, and have a poor road safety record. This comparative evaluation of USA 'concept safety' ambulances and a standard Australian ambulance is based on basic principles of crashworthiness and available crash test data. There are features of USA ambulance design that are not within known principles and technical aspects of crashworthiness and safety design, and include some predictable serious occupant protection hazards. The USA ambulance industry should recognize and apply crashworthiness and occupant protection principles to reduce current system failures for this fleet of essential service vehicles.

INTRODUCTION

Ambulance vehicles are a unique passenger vehicle in both design and purpose. This vehicle is one of the only vehicles on the road that has occupants positioned in numerous diverse seating positions in the rear compartment - recumbent and seated (forward, rear and side facing) and also in some situations ambulant (ref 1, 2). Compounding the challenges of this occupant arrangement, this is also a vehicle that during emergency response mode, travels at high speed and with risky driving practices. These practices are well described to be hazardous and likely to result in crashes, the most serious outcomes resulting from driving across intersections, and against a red light or stop signal (ref 3,4). Not surprisingly the data over the past decade has now very clearly highlighted ambulance transport in the USA as being a high risk mode of transportation (ref 5). It is clear that improved ambulance policies and operational procedures and technologies (ref 1, 2) can minimize the transportation hazards. However the data strongly points to the rear occupant compartment of the ambulance as being of high risk of serious injury and fatality in the event of a crash (ref 3). The safety

performance record for ambulance vehicles does not appear to be uniform globally – and the estimates comparing ambulance crash fatality rates for the USA and Australia demonstrate that the USA is up to 35 times more lethal per capita than Australia. There are a number of differences in the structure of these two systems, in policy and operational procedure as well as in the design and construction of the ambulance vehicles. Also, and importantly for this study there are major differences in the oversight and design standards for ambulance safety and occupant protection in USA compared to Australia. Since 1999 Australia has had an Australian Standards Association (ASA) approved ambulance restraint standard to address some of the occupant protection issues for the rear occupants of an ambulance (ref 6). This paper will discuss vehicle design and safety issues.

BACKGROUND

Prior to describing the specific ambulance vehicle comparisons, it is key to first address in some detail the design and manufacturing approach for ambulance vehicles in the USA and Australia. There is some variation within each country, however there are features more characteristic of ambulance design and manufacture specific to each country. Additionally the system of oversight and design standards and the development of those standards differ quite dramatically between the USA and Australia, as does the existing research base.

AMBULANCE MANUFACTURE – The majority of ambulance vehicles in the USA are made from an after market rear occupant box, built by a non-automotive industry manufacturer who also attaches the box to an automotive industry built chassis. The occupant safety aspects of such rear compartments are essentially under the purview of that retrofitting industry (see below). There are also some van type vehicles in use in the USA where aftermarket manufacturers remove the roof, (which

is part of the integral vehicle structure), and replace it with a roof extension that is not fitted by the Original Equipment Manufacturer (OEM) of the vehicle nor has this fitment been crash tested. In contrast, in Australia, the majority of the ambulance vehicles are automotive industry built vans – without structural alteration by the aftermarket retrofitters. The standards involved are discussed below.

AMBULANCE DESIGN STANDARDS AND SAFETY OVERSIGHT – In contrast to the general passenger vehicle industry, there are few reviews published of the design standards and the oversight of the safety of ambulance vehicles in the USA or Australia. The development of the ambulance industry differs somewhat, having begun in the USA as an off shoot of the mortician industry in a hearse type of passenger vehicle and then migrated into a cargo or motor home design in the 1960's. At that time, the rear passenger box was built by aftermarket manufacturers – outside of automotive technology and the automotive safety industry. At some point around that time, exemptions from the USA Federal Motor Vehicle Safety Standards (FMVSS) were sought and granted for most aspects of occupant protection and safety for ambulance vehicles' rear compartment. Those exemptions are still in existence. USA ambulance vehicle standards have remained outside of the automotive safety industry, and have been developed by the after market retrofitters themselves. This has been, and continues to be, under the auspices of their own professional association, the Ambulance Manufacturing Division (AMD) of the National Truck Equipment Association (NTEA). This organization, the AMD, has not developed any other vehicle standard and is an organization that is not under the oversight of the automotive safety industry. The ambulance industry in Australia developed differently with a focus specifically on patient transport from the outset. Of note, Australia was also the first country globally to have civilian air medical transport, in 1928, namely the Royal Australian Flying Doctor Service. Thus there was a focus on ambulance transport separate from the mortician industry in Australia. The safety of Australian ambulance vehicles was subjected to accepted automotive safety evaluation and testing by government entities in the 1980's, if not before. The worlds first automotive and occupant protection standard for ambulance vehicles was developed in Australia in 1999 (ref 6). This was developed by the ASA, same entity that addresses other aspects of automotive occupant protection. This ambulance restraint standard embraces accepted automotive safety practices and procedures - and is published as an official standard by the Australian Standards Association (ref 6).

USA Ambulance design and safety standards – The specifications and standards for ambulance safety and design in the USA are somewhat unique in their approach and development. They are not compiled by the automotive safety industry but rather by the General Services Administration (GSA) in the KKK-F (replacing the previous version, KKK-E), Star of Life Ambulance

purchase specification (ref 7). In addition, the aftermarket ambulance manufacturers themselves have developed their own standards, the AMD 001-025 Ambulance Standards (ref 8). Furthermore, the GSA is an organization that has not compiled any other vehicle safety performance or occupant protection standard. The AMD similarly has not ever compiled any other vehicle or occupant protection standard. The AMD ambulance standard when recently subjected to independent automotive safety engineering peer review was demonstrated to be both deficient and misleading (ref 9). It was not in keeping with accepted automotive safety science or engineering.

The KKK-F (and E, the previous version) specifications and the AMD Standard, reference and default on many safety issues to the Federal Motor Vehicle Safety Standards (FMVSS). However the FMVSS sections to which they default to have specific exemptions for ambulance vehicles rear passenger compartment or box (ref 10). These exemptions apply to any occupant or structure located 600mm behind the seating reference point of the driver of the ambulance vehicle (ref 10). The AMD standards, developed internally by the AMD, make numerous references to FMVSS compliance even though the FMVSS documents cited have specific exemptions for ambulance vehicles.

GSA KKK-F - is a government purchase specification (ref 7). Compliance with this specification is required for any government ambulance purchase. This has become a proxy general 'standard' for ambulance design. It however has limited, if any, meaningful automotive safety and crashworthiness or occupant protection technical information. For example:

- No requirement for dynamic impact or crash testing
- No requirement for anthropomorphic test devices.
- References FMVSS, for which however there are specific exemptions for ambulance vehicles

AMD 001-025 standards - are a set of specific design standards developed and approved by the AMD of the NTEA (ref 8). This is the standard driving design for the ambulance industry in the USA. It not only has limited, if any, meaningful automotive safety and crashworthiness or occupant protection technical information, there are many statements within that standard that are well outside of any accepted technical automotive crashworthiness and safety practice (ref 9). These standards make claims that are misleading, particularly to the engineer not trained in automotive safety and crashworthiness. This standard states that the static testing it proscribes offers demonstrated protection that would mitigate injury under vehicle impact and crash circumstances. This is a misleading statement.

Furthermore a quote from the AMD standards further demonstrates the failure to consider known automotive occupant protection and safety principles, such as crumple zones. The standard suggests that if a successful test there should be *"No structural damage*

to any load bearing or supporting members, i.e., torn or broken material, broken welds, popped or sheared body rivets, bolts, and/or fasteners, shall be evident during the application of the force and after the release of the force".(ref 9 Section 5. c.) Also it should be understood – that such tests are static load tests that do not include any inertia effects resulting from deceleration nor occupant crashworthiness kinematics. For example:

- No requirement for dynamic impact or crash testing
- No requirement for anthropomorphic test devices.
- No references to any injury criteria
- References FMVSS, for which however there are specific exemptions for ambulance vehicles
- Specifically exempts the walls as potential head strike zones, even though there is extensive injury data to identify this as a primary injury hazard in a crash or sudden deceleration

Interestingly, in a document published by the AMD and posted on their web site (circa 2006), – titled "AMD Position Statement on Ambulance Safety and Occupant Protection" (ref 11) - it clearly references that ambulances must abide by the FMVSS 49 517, the FMVSS that specifically exempts ambulance vehicles (ref 10).

USA Ambulance safety oversight – There is no specific national or even comprehensive state oversight over the safety of ambulance vehicle performance. The vehicles are inspected for licensing and registration purposes – but this inspection and licensing does not include any assessment of occupant crash protection or crashworthiness performance. In addition to the FMVSS exemptions, ambulance vehicles are exempt from Federal Motor Carrier Safety Administration (FMCSA) oversight (ref 12), thus national data for ambulance vehicle safety and crash events is not available for ambulances as it is for other commercial vehicles.

USA Ambulance vehicle testing and research - As is well described in the passenger vehicle safety industry, a key issue is that vehicle safety testing should be based on real world crash and injury data. The nature and mechanism of ambulance crashes and the injuries sustained has had limited attention. What has been clearly described is that in an urban setting intersection crashes appear to be the most frequent serious injury crash event. This is often a side impact crash with the ambulance as the bullet vehicle (frontal impact) and involving a small passenger vehicle (side impact). In a rural setting it appears to be single vehicle events are more common, and often involve narrow fixed object impacts. Given this crude profile, and that the majority of the mass of an ambulance is at the vehicle's rear compartment behind the front cab, the mechanics of an ambulance crash differs from that of a passenger vehicle. In previous research conducted by the authors (ref 13-17) vehicle to vehicle crash test scenarios were carried out which replicated real world crash data and outcomes. These tests involved a van ambulance striking a box chassis style ambulance, and also a box

chassis ambulance striking a van ambulance, to replicate a characteristic more serious real world event. Of note a USA group recently published a series of tests conducted some 5 years prior to their publication (ref 18). These tests were of a fully loaded ambulance impacting a rigid barrier. It is likely that this configuration does not represent real world ambulance crash forces. Interestingly – the vehicle crush profiles in that testing did not represent characteristic real world ambulance vehicle crush profiles. These tests were apparently conducted in the absence of population based real world ambulance injury data, nor were there any references in that publication to any existing published engineering work in the field. It is of concern that any recommendations for general ambulance crash test protocols should be based on testing that has been conducted in this fashion.

Australian Ambulance design and safety standards – The specifications and standards for ambulance occupant safety and design in Australia are via the ASA (ref 6). This is a standard compiled by representative experts from a number of areas of automotive safety and occupant protection. It is a standard that is based on the fundamental principles of automotive safety and occupant protection and it involves dynamic impact testing with Anthropomorphic Test Devices (ATDs), (ref 19). Additionally, the ASA is a standards organization that is active in the establishment of standards for a number of automotive and occupant safety applications.

Australian Ambulance safety oversight – There is both national and state oversight over ambulance safety in Australia. Each state has direct operational oversight over the ambulance system, as it is a governmentally overseen public service industry. Comprehensive data is collected by each state on system adverse events. The vehicles are inspected for licensing and registration purposes – to ensure they comply with the Australian standard.

Australian Ambulance vehicle testing and research - Australia was involved in conducting some of the earlier ambulance safety and crashworthiness research globally. In the early 1990's (ref 20) a rollover ambulance crash test was conducted by the Victorian government, followed by some sled work addressing occupant protection in South Australia (ref 21), and in the mid 1990's some sled test work addressing pediatric patient occupant safety issues, by the authors (ref 16). These studies were driven by real world practice crash events and data.

SAFETY CONCEPT VEHICLE ANALYSIS

METHODS - Five recently designed ambulance vehicles were identified and compared. Four were from the USA and one from Australia. This evaluation is a broad based evaluation of basic and fundamental aspects of crashworthiness, occupant protection and safety design features. It is based on crashworthiness tests conducted by the authors and other agencies of some