

# DEVELOPMENT OF PROPOSED CRASH TEST PROCEDURES FOR AMBULANCE VEHICLES

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## ABSTRACT

Ambulance vehicles are a unique passenger environment with complex crashworthiness and occupant protection issues, eg. occupants in various orientations, unique human factors aspects and an array of aftermarket interior modifications. In the USA, ambulance vehicle occupant protection, crashworthiness and safety testing lags 30 years behind current general automotive safety technology. This paper proposes crash test procedures and outlines some of the challenges faced for such vehicles based on manufacturer and consumer conducted pre-modification crash tests and previous ambulance sled and full scale crash tests.

A typical ambulance vehicle from one of the largest fleets globally, was addressed. Based on manufacturer specifications, crash test data for the vehicle, inspections and other published data regarding ambulance vehicle crashes, sled and crash testing were considered – an approach to an impact testing procedure is outlined and developed by a multidisciplinary team.

Assessment and development focused on vehicle crashworthiness performance and real world human factors aspects of aftermarket interior modifications. Frontal and side impact crashworthiness testing profiles for this vehicle were determined and developed inline with parameters outlined in ASA 4535 (ambulance restraint systems standard) and the CEN 1789 standard. The testing profiles include a recumbent occupant, rear and forward facing seated occupants, 50<sup>th</sup> and 95<sup>th</sup> percentile ATDs, including side impact ATDs for seating positions exposed to side impacts.

The authors propose that ambulance vehicle safety testing and design should be driven by accepted automotive safety practice. In a setting of high crash rates, a complex occupant and emergency care environment, and the absence of prescribed dynamic

crashworthiness test procedures for ambulances - the proposed test procedures in this paper provide a first approach to describe the approach to the technical development of comprehensive crash testing profiles in this setting. Such profiles for this environment will ensure that system safety can be ascertained and optimized for these vehicles, and support safety enhancements and occupant protection for ambulance vehicle development.

## INTRODUCTION

Emergency Medical Service (EMS) vehicles, ambulances, are relatively familiar vehicles to the community in general. They are perceived as ‘life savers’ racing through the streets to provide emergency medical care to the public. It is the vehicle that comes to rescue crash victims on roads and highways. However, what are the safety issues that pertain to this important public service and public safety vehicle? How safe are these vehicles and to what standards are they designed and tested?

EMS is a relatively new industry, an industry that has an unusual history of beginnings within the mortician industry. The first modern ambulances were hearses, usually a Cadillac, a vehicle in which an occupant could be transported in the recumbent position. Over the past 30 years, the sophistication of the medical care possible to provide in the EMS environment has advanced dramatically, with EMS providers over that short time becoming highly skilled and expertly trained emergency health care professionals – with use of high tech medications and equipment. However, the vehicle occupant safety issues pertaining to the delivery of EMS care have not kept pace with the advancement of the medical emergency care provided. Nor has EMS vehicle safety kept pace with the developments in automotive safety. This is possibly due to the ambulance graduating from the Cadillac to a combined chassis with a mounted box, somehow outside of the purview of both automotive safety and also occupational safety and health arenas.

Compounding this also is that ambulance vehicles in many parts of the world are a very diverse fleet: vans, light and heavy trucks and freightliners. Despite the large strides the general automotive industry has made in the last 30 years in passenger vehicles occupant protection and passive and active safety, this expertise has not yet translated substantively to the safety of ambulance vehicles particularly in the USA.

There are few safety standards and no crashworthiness safety test procedures and guidelines that pertain to ambulance vehicles in the USA and very limited safety testing requirements in Europe established in 1999 (CEN1789). Australia has had the ambulance restraint standard ASA 4535 in place since 1999 (AS/NZS 4535:1999), and it is the most stringent to date globally. Thus ascertaining the safety of EMS transport vehicles (and products in that environment) remained limited largely to expert opinion and peer evaluation in a piecemeal fashion until 1999 in Australia and 2000 in Europe, and still remain so in USA.

EMS in the USA has been generally demonstrated recently to be a dangerous profession, and vehicles crashes have been shown to be the most likely cause of a work related fatality in EMS (Maguire 2002). The most dangerous part of the ambulance vehicle has been demonstrated in both biomechanical and epidemiological studies to be the rear patient compartment (Becker 2003, Levick 2000-2001), which currently is a part of the ambulance vehicle that is largely exempt from the USA Federal Motor Vehicle Safety Standards (FMVSS 49CFR).

There is approximately one ambulance crash fatality per week in the USA, and a number of serious injuries for each fatality, with over 4,000 reportable crashes per year (Becker 2003). Unfortunately in the USA, no national reporting system or database exists specifically for identifying ambulance crash related injuries and their nature. Hence, specific details as to which injuries occurred and what specifically were the mechanisms which caused them are scarce, and there is not yet a national system for this data capture. What we do know is that ambulances have high crash fatality rates per mile, well above those of passenger vehicles, or even when compared to similar sized vehicles (Ray 2005) and also when compared to buses and trucks (FMCSA). There are numerous reports of serious injury occurring from loose equipment becoming projectiles, and occupants being ejected from vehicles - all issue that can be addressed with a combination of restraint standards for occupants and equipment – and practice policies

mandating the use of such restraint systems.

There has been a limited number of peer reviewed automotive safety engineering testing conducted for the EMS environment in Sweden (Turbell 1980), Australia (Best 1993, Levick 1998), and the USA (Levick 2000-2001). That which has been conducted has clearly identified some predictable and largely preventable hazards, particularly pertaining to intersection crashes and the hazards of the rear patient compartment, demonstrating the benefit of use of existing restraints for occupants, the importance of over the shoulder harnesses for the recumbent patient and firmly securing all equipment (Best 1993, Levick 1998-2001). These studies also identify hostile and hazardous interior surfaces of the rear compartment, as well as a need for head protection. Many fatal and injurious ambulance crashes occur at intersections, failure to come to a complete stop has been identified as an extremely high risk practice, Lack of use of seatbelts by EMS personnel is cited frequently in the literature as a predominant cause for the high injury and fatality rates for occupants in EMS crashes (Becker 2003). The hazards resulting from the failure to secure equipment in the patient compartment, which has also been found to cause serious injury in the event of a collision has also been documented. This is supported by the engineering data from ambulance safety research involving crash tests (Levick 2001), as well as insurance and litigation records. With ambulance crashes being identified in the USA as the highest cause of patient adverse event mortality and serious morbidity (Wang 2007)

### **Existing Ambulance Standards**

Prior to 1999 there were no dynamic safety performance standards for ambulances globally. The first nationally approved safety performance standard was the Australian ASA 4535, in 1999 that required dynamic impact testing of the components in the ambulance vehicle, and the use of a 50<sup>th</sup> percentile and a 95<sup>th</sup> percentile, anthropomorphic crash test dummy (ATD) with a 24 G impact test forward and rear and 10 G laterally.

The CEN followed, implemented in 2000 in Europe, requiring safety performance testing to 10 G forward, rear, laterally and vertically, being a much reduced severity level. There is a 2006 revised draft currently under review.

Both the ASA and CEN are mandated and not voluntary.

The very recently developed USA American National Standards Institute/American Society of Safety Engineers Z15.1 Fleet Safety Standard (ASSE/ANSI 2006) is possibly the only nationally approved fleet safety standard that is now applicable to the safety management of EMS vehicle fleets in the USA. It requires that the vehicles be crashworthy and safe – yet, in the USA there are no crashworthiness standards for these vehicles. The GSA KKK ambulance vehicle specification guideline, currently version E and soon to be updated to version F – is a purchase specification and not a safety performance standard (GSA KKK), and does not provide for guidelines for any dynamic crash testing – rather simply static tests. Moreover it has no automotive safety crashworthiness impact performance requirements. It does make reference to the Federal Motor Vehicle Safety Standards – however in the USA ambulances have a specific exemption from that standard (FMVSS). Also the GSA KKK is a voluntary specification and compliance is not mandated. It is likely that the implementation of the new ASSE/ANSI standard will enhance the data collected regarding EMS vehicle safety, and hopefully provide more emphasis on EMS vehicle safety generally and assist in bringing EMS vehicle safety more inline with state of the art automotive safety practices.

### **Study focus vehicle selection**

Much of Europe, Scandinavia, Asia and Australasia currently use fleets of automotive industry designed and manufactured vans with specialized aftermarket additional retrofits to adapt them to the ambulance market. There is decreasing presence of the chassis with aftermarket box outside of the USA.

There are some interesting challenges pertaining to ambulance vehicle crashworthiness. Asides from the fact that the CEN standard is a less severe impact testing profile than the ASA standard, both are standards which only require deceleration/acceleration sled testing. In other words these are tests of stability and safety performance of the retrofit under acceleration/deceleration conditions – in contrast to structural crashworthiness testing of the whole vehicle with impact, barrier or full vehicle deforming and intrusion crash tests.

This is an important aspect of the safety and safety testing of these vehicles. Vehicles manufactured by the automotive industry are complete vehicles subjected to sophisticated structural and automotive crashworthiness design, testing and oversight prior to their retrofit. Furthermore, any ambulance retrofits

built into structurally modified vehicles or the chassis/box design, may well not share safety performance of ambulance vehicles with retrofits built into an intact automotive industry manufactured vehicle, where there are no structural modifications. In the case of the chassis /box type of ambulance – in the USA there has been no formal sophisticated automotive industry dynamic or impact structural and automotive crashworthiness impact design, testing and oversight in the manufacture of the rear passenger compartment box asides from the research conducted by the authors (Levick 2000-2001), and one project conducted in Canada, for which comprehensive findings are still pending. In the USA there is currently no requirement or parameters by which to dynamically crash test the rear compartment box or the chassis/box combination.

Thus the ambulance retrofit into a complete intact automotive industry designed and manufactured vehicle such as a van, is in a vehicle which has already a high degree of structural crashworthiness design and testing at the outset by the original automotive manufacturer – so a basic deceleration/acceleration sled test is more a test of the safety performance of the retrofit modifications, and rather than a test for the safety of the vehicle as a whole. Albeit that there does exist some useful indication of general vehicle safety and crashworthiness performance with acceleration/deceleration dynamic testing. Thus the testing of the performance of the retrofit and equipment mounts are somewhat of an additional issue beyond the whole vehicle's crashworthiness including intrusion and vehicle structural deformation and crashworthiness for a vehicle that has already been subjected to this type of testing. However it is understood that the retrofit may perform differently to some degree in a setting of vehicle deformation and intrusion. In the setting of the chassis/box design – these rear occupant compartments are not produced by the automotive safety engineering and manufacturing industry and are not required to be dynamically safety tested in the USA by automotive industry manufacturers. Thus if the only dynamic impact testing these aftermarket chassis/ box combination vehicles are subjected to would be a deceleration/acceleration test – this is a test that does not involve any automotive structural deformation crashworthiness testing but is simply the deceleration test of the retrofit. Thus the safety of the chassis/box construction under true impact, deformation and intrusion conditions cannot be effectively demonstrated with the existing ambulance testing standards, either CEN or ASA. Although the ASA and CEN may give some indication of the

performance of the retrofit under deceleration conditions – it does not address the combined vehicle and retrofit performance structurally under impact crashworthiness conditions in the real world setting of a crash – where intrusion occurs.

For these reasons additionally, the vehicle selected here for this paper was the automotive industry manufactured intact structurally unmodified van and not the combined box and chassis vehicle, and also not a van that has undergone any structural after market modification. For those vehicles the research team suggests that this form of testing is suboptimal.

### **Approach to Crash Test Profiles**

Configuration of ambulance vehicles to reflect real world practice and within realistic parameters of anthropometric test devices (ATDs) for each test procedure are key aspects of safety testing of ambulances. Ambulances differ from other passenger vehicles in that the occupants are oriented in a range of seating and lying positions and the medics are trying to perform clinical and emergency care during transport. Although in only less than 5% of transports is it life threatening care. Additionally there is often heavy equipment in close proximity to occupants, such as oxygen cylinders and cardiac monitors.

Despite the comparatively small market of the ambulance retrofit industry when compared to the general automotive market – it is important that testing requirements and standards be designed to address real world risks and hazards for the occupants of these vehicles. In the general automotive industry – crashworthiness testing is driven strongly by real world injury data, with the design and ongoing development of the New Car Assessment Program (NCAP) testing (EuroNCAP, USA and Australian NCAP). However, real world injury data on ambulance occupants for each vehicle and retrofit type is at best limited, if available at all. Also, the ambulance environment is an unusual environment where occupant protection is impacted by both realms of vehicle and interior design and also practice policy. Policies such as seat belt use, equipment required to be carried on the vehicles and procedures that are required to be performed all have bearing on what design and testing is appropriate. This makes the design of testing procedures very complex – Additionally, given the expense of testing for this small niche market, it is important that the testing procedures are not redundant – ie. requiring protection in a part of the vehicle that has no injury hazards described. For example, if it were that the occupants were to be seated and belted at all times in

a moving vehicle then the focus of interior design and testing may differ if this was not the case. Challenges faced by the ambulance retrofit industry in Europe are two fold: one that any testing required be testing that improves safety and outcome, and two that the ‘standard writing’ process is voluntary - and participation is not reimbursed and thus that active input from the retrofit manufacturers is likely to be minimal due to the expense of participation in the process. Hence there are concerns from the retrofit manufacturers regarding the concept of safety testing standards in the absence of real world injury data and also the practical challenges for their input to be included.

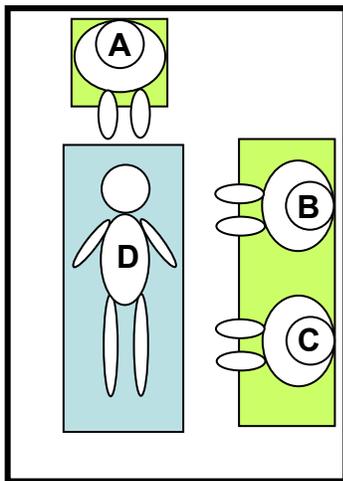
Recent epidemiologic data describes frontal impact, right side impact and rollover as the most frequent mechanisms that occur with serious morbidity and mortality in the USA – often the result of intersection crashes.

An additional challenge is that in most USA ambulances, the right hand side of the vehicle is fitted with a ‘squad bench’ – a structure that has minimal if any automotive safety features. And this is a structure which has been described in previous military vehicle crash testing to be a hazardous mode of occupant transport in a forward traveling vehicle (Richardson et al 1999, Zou et al 1999).

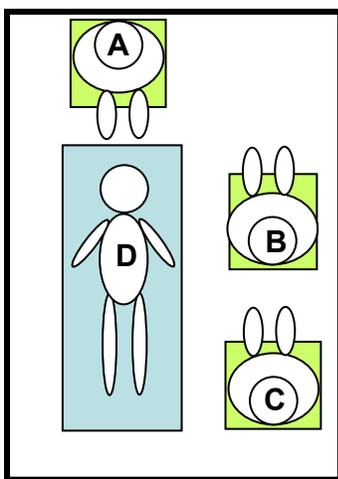
Also as per the ASA 4345 standard occupant seating in the ambulance vehicle is required to include 50<sup>th</sup> - 95<sup>th</sup> percentile male ATD. The seating position options include rear facing captains chair, one to three occupants on the right sided ‘squad bench’ seated sideways facing toward the left wall over the vehicle - and a recumbent patient (See Fig 1). Some USA ambulances also have a seated occupant in a small seat (the CPR seat) in the middle of the cabinetry on the left wall of the ambulance. Although most USA ambulances are configured with a squad bench – and some the CPR seat, the new proposed KKK – F purchase specifications do not mandate a squad bench. Thus a testing profile should consider the possibility for a similar occupant layout as in the European and Australian ambulance vehicles. Neither the testing profiles for the European ambulance vehicles, nor the testing profiles for the Australian ambulance vehicles specify a side impact ATD for the occupants seated in seating positions vulnerable to a side impact crash.

So there are fundamentally three issues that appear to have bearing on the real world applicability of existing testing profiles of ambulance vehicles: one is the difference between acceleration/deceleration

testing of the retro fit separately from full crash and deformation testing of the full vehicle with the retrofit in place, the second is the use of a side impact ATD for occupants involved in a crash scenario where they would be seated sideways, and thirdly the limitation of real world injury and crash data for guiding design and testing profiles. These three issues are also confounded to some degree by the impact of practice policies on the potential for specific risks and hazards – as well as the broad spectrum of ambulance vehicle configurations in the USA, and that currently that those designs are strongly being driven by end users who have no formal background in automotive safety.



**Figure 1. Seating positions as per. As per current USA ambulance layout – Test Plan 1**



**Figure 2. Seating positions as per anticipated USA ambulance layout post KKK F release, with only forward and rear facing seats – Test Plan 2**

## Test procedure

As stated above, given that the chassis/box style vehicle is not crash tested as a unit prior to retrofit it is felt that the testing profile of this vehicle would not be included within the constraints of this paper and that the profiles discussed here will be restricted to application in the setting of an automotive industry built structurally intact van with an ambulance retrofit that does not interfere with the original vehicle structure. The chassis/box combination would require more extensive and detailed testing, including full vehicle testing to ascertain the crashworthiness of the structure as a whole and to be deemed safe for occupants than this profile provides.

Also there is no specific ATD for a recumbent patient – so a standard 50<sup>th</sup> percentile ATD such as a Hybrid III with articulating legs, is suggested in this testing for the recumbent occupant, although the existing standards suggest that a simple mass object could replace the recumbent occupant. Given that the effectiveness of the recumbent occupant restraint system has been demonstrated to be a potential injury hazard – this opportunity to evaluate that system should be considered. For each test where seated occupants are subjected to a side impact force – a side impact ATD should be used to demonstrate more accurately what the hazards are for that occupant and the restraint of that occupant. Ascertaining which sized ATD should be in which seating position is challenging as there is no population data to describe the real world situation.

The test procedure described here attempts to address testing that reflects the safety of real world practice and under real world conditions.

For frontal and rear collision, from the limited crash data that exists – it appears that USA ambulances are most frequently involved in frontal high speed and rear lower speed impacts. As such a test procedure as outlined in the ASA for frontal impact of 24 G and a rear impact of 10 G as specified in the CEN could also be considered appropriate. The nature of the ATDs for each position, should reflect real world practice, and the 50<sup>th</sup> and 95<sup>th</sup> percentile ATDs as described in the ASA standards address the size spectrum of ambulance occupants. The restraint configuration used should be the restraint configuration to be implemented in the on road vehicle – and restraint of medics, patient, and other occupants, key equipment such as oxygen tanks, sharps containers and cardiac monitors as well as medication bags and communications equipment should be addressed.

There is much discussion in the literature regarding the optimal restraint configuration for a side facing occupant in a forward moving vehicle. Ideally the floor plan for Test Plan 2 provides more optimal occupant protection for all occupants in a frontal or rear crash, and likely also a side impact when compared to Test Plan 1's layout.

It is unfortunate that the side of the vehicle that is most frequently struck in a side impact, is the right side of the vehicle (due primarily to the driver being on the left). It is also the side of the vehicle that has the most seated occupants. However as there are other issues that come into play regarding the access to the vehicle and the safety of that with respect to road traffic this is likely to be a feature of the ongoing design of ambulance vehicles in the USA. An important aspect to consider in the testing is for the correct type of ATD to be in the positions that coincide with the location of occupants in the real world setting.

The following are possible test procedures that could be applied in this environment. They are based on current ASA and CEN documented and mandated test requirements. However the authors note that there are no injury criteria (NHTSA) associated with these published requirements, never the less these procedures could act as a first step to bring the USA up to current world practice. Even though the authors believe these procedures as described, are deficient.

### **Frontal**

In the longitudinal direction with a 50<sup>th</sup> percentile ATD in forward or rearward seating positions A, B, C, D. When the test rig (sled) is subject to a velocity change of not less than 49 km/h in the forward direction, a deceleration of between 24g and 34g shall be achieved within 30 milliseconds. The deceleration shall remain within the range of 24g to 34g for not less than 20 milliseconds, deceleration values outside this range that occur for period of not greater than 1 millisecond may be disregarded.

In the longitudinal direction with a 95<sup>th</sup> percentile ATD in forward or rearward seating positions A, B, C, D. When the test rig (sled) is subject to a velocity change of not less than 49 km/h in the forward direction, a deceleration of between 18.2g and 26g shall be achieved within 30 milliseconds. The deceleration shall remain within the range of 18.2g to 26g for not less than 20 milliseconds, deceleration values outside this range that occur for period of not greater than 1 millisecond may be disregarded.

### **Rear**

In the longitudinal direction with a 50<sup>th</sup> percentile ATD in forward or rearward seating positions A, B, C, D. When the test rig (sled) is subject to a velocity change of not less than 32 km/h in the rear direction, a deceleration of between 12g and 22g shall be achieved within 30 milliseconds. The deceleration shall remain within the range of 10g to 17g for not less than 20 milliseconds, but deceleration values outside this range that occur for periods of not greater than 1 millisecond may be disregarded.

For the 95<sup>th</sup> percentile ATD, when the test rig (sled) is subject to a velocity change of not less than 32 km/h in the rear direction, a deceleration of between 9g and 19g shall be achieved within 30 milliseconds. The deceleration shall remain within the range of 10g to 17g for not less than 20 milliseconds, but deceleration values outside this range that occur for periods of not greater than 1 millisecond may be disregarded.

### **Right Side Impact**

For the squad bench layout Test Plan 1, the 50<sup>th</sup> and 95<sup>th</sup> percentile manikins could be utilized for this test in that seating position. However, for the Test Plan 2 layout, in the side impact test – the side impact ATD should be utilized.

For the 50<sup>th</sup> percentile ATD, when the test rig (sled) is subject to a velocity change of not less than 32 km/h in the lateral direction, a deceleration of between 12g and 22g shall be achieved within 30 milliseconds. The deceleration shall remain within the range of 10g to 17g for not less than 20 milliseconds, but deceleration values outside this range that occur for periods of not greater than 1 millisecond may be disregarded.

For the 95<sup>th</sup> percentile ATD, when the test rig (sled) is subject to a velocity change of not less than 32 km/h in the lateral direction, a deceleration of between 9g and 19g shall be achieved within 30 milliseconds. The deceleration shall remain within the range of 10g to 17g for not less than 20 milliseconds, but deceleration values outside this range that occur for periods of not greater than 1 millisecond may be disregarded.

## Vertical

This test is to provide for safety performance in the setting of an aspect of a rollover situation. Clearly this is not a rollover simulation – but a proxy for the performance of the ambulance retrofit in this orientation for impact. Ideally a roll over test would provide far more comprehensive and valuable information, however this may not be realistic to achieve in the real world setting of this particular industry at present. The ASA 4535 does not include a vertical component. Nevertheless, given the nature of ambulance crashes – it is felt by the authors that this test should be included in this test profile. For a 50<sup>th</sup> percentile ATD, when the test rig (sled) is subject to a velocity change of not less than 32 km/h in the vertical direction, a deceleration of between 12g and 22g shall be achieved within 30 milliseconds. The deceleration shall remain within the range of 10g to 17g for not less than 20 milliseconds, but deceleration values outside this range that occur for periods of not greater than 1 millisecond may be disregarded.

For the 95<sup>th</sup> percentile ATD, when the test rig (sled) is subject to a velocity change of not less than 32 km/h in the vertical direction, a deceleration of between 9g and 19g shall be achieved within 30 milliseconds. The deceleration shall remain within the range of 10g to 17g for not less than 20 milliseconds, but deceleration values outside this range that occur for periods of not greater than 1 millisecond may be disregarded.

## CONCEPTUAL DISCUSSION

This paper presents a basic and initial step in addressing the automotive safety testing and safety performance standards for ambulance vehicles in the USA. The testing parameters put forward in this paper have been modeled on the existing two accepted and ratified ambulance safety performance testing standards, ASA 4535 and CEN 1789, thus these are recommendations that are within the currently available ASA and CEN standards. Whilst the authors would like to see changes in the USA ambulance safety and crashworthiness practice and standards incorporating these suggested requirements as outlined in this paper - It is clear that what has been suggested here is but a first step. These requirements are in no way regarded as adequate from an automotive safety engineering perspective. True vehicle performance and crashworthiness safety standards should include comprehensive real world crash data, full vehicle crash test data, include formal injury data and address known injury criteria, and

embrace active involvement of the automotive safety engineering industry as is accepted practice in the field of automotive safety engineering.

Regarding specific aspects of the USA ambulance vehicle interior retrofit, an issue that is of major concern is that the practice of use of a side facing ‘squad bench’ – a structure constructed devoid of automotive safety principles (Richardson et al 1999, Zou et al 1999) – This issue should be addressed in the USA in a similar fashion as Europe and Australia - ie. discontinued – there is no supporting medical evidence for its need, and extensive automotive safety evidence that it is a dangerous occupant practice- both in the setting of frontal and side impacts, as well as of limited ergonomic function. Additionally, in the setting of side impacts, even with the use of automotive designed seating forward or rear facing - the issue of side impact protection is of concern. A potential solution to this is to design a seat for this environment that integrates some side impact head and upper body protection.

Importantly there is no reference to any injury criteria, for example, the HIC or chest decelerations (NHTSA) - this is of great concern particularly given two data points. One being that ambulance vehicles in the USA have a specific exemption from FMVSS CFR 49 517 (for head impact protection) and secondly that it has been documented that serious head injury is associated with greater than 60% of rear occupant fatalities.

Furthermore, it is the opinion of the authors that for ambulance vehicles which are not retrofits of intact and structurally unmodified automotive industry complete vehicles (structurally intact vans) – such as the chassis and box design or also retrofits of vans that involve any structural modifications that may affect crashworthiness performance, that standards such as the CEN and the ASA are inadequate for demonstrating the occupant safety of such combination or structurally modified vehicles. In such circumstances, with structurally modified vehicles or combination vehicles, demonstration of occupant safety and crashworthiness would require full vehicle crash testing – simple deceleration/acceleration testing of an intact vehicle shell may not provide meaningful results – particularly at 10G - as deformation of the structure of the shell via intrusion is not able to be modeled in a simple deceleration/acceleration test. There is much evidence from real world crash ambulance crashes, even relatively low speed intersection collisions or collisions involving fixed objects that there are serious occupant hazards and failures of occupant

protection of the chassis and box type of ambulance design, particularly for the rear compartment occupants. It remains an irony that the occupant protection for the rear compartment of vehicles carrying laundry and packages is no different from a dynamic impact crashworthiness perspective than for these chassis box combination ambulance vehicles carrying our emergency providers, patients and next of kin in the USA.

## CONCLUSIONS

Emergency medical service transport is occurring in a setting where its own vehicle safety has been identified as less than optimal in the USA. Ambulance vehicle design and safety testing should be driven by accepted automotive safety and engineering practice. In a setting of high crash rates, a complex occupant and emergency care environment, and the absence of prescribed dynamic crashworthiness test procedures for ambulances - the proposed test procedures in this paper provide a first approach to describe the technical development of comprehensive crash testing profiles in this setting in the USA. Ambulance vehicles that are not intact automotive industry manufactured vehicles, or are structurally modified cannot be demonstrated to be safe for occupants in the rear compartment in the absence of full vehicle dynamic impact testing to demonstrate intrusion. Additionally, use of design features such as a non automotive designed side facing squad bench should be avoided given the challenges in addressing both occupant safety and the provision of patient care with this orientation. Such profiles as outlined in this paper for the ambulance environment could ensure that vehicle design and vehicle system safety can be ascertained and optimized, and also support safety enhancements for ongoing ambulance vehicle development.

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