Analysis of factors affecting ambulance compartment integrity test results and their relationship to real-world impact conditions.

G Mattos*, K. Friedman*, J Paver**, J Hutchinson*, K Bui* & A Jafri*

*Friedman Research Corporation, 1508-B Ferguson Lane, Austin, TX 78754
** Center for Injury Research, Santa Barbara, CA, 93109

Abstract - A Society of Automotive Engineers (SAE) recommended practice for ambulance modular body evaluation (SAE J3057) was issued in February 2017. This test method is referenced in current U.S. General Service Administration (GSA) purchasing requirements (KKK-A-1822F, Change Notice 10, July 1, 2017) and is expected to be included in the 2019 edition of the National Fire Protection Association (NFPA) 1917 and the next iteration of the Ground Vehicle Standard (GVS). The test method is a two-phased protocol which includes an initial dynamic impact followed by quasi-static loading of the modular body compartment. The protocol for the dynamic loading event was developed based on the accelerations and forces measured from rollover tests of exemplar ambulances using three methods (corkscrew, tip up (ECE R66 type test), and FMVSS 208 style dolly rollover tests). Due to the requirements inherent in defining repeatable test procedures, some of the test criteria and boundary conditions may not be representative of actual rollover crashes.

Keywords: Finite Element Analysis; Ambulance; Rollover; Structural Crashworthiness; SAE J3057

INTRODUCTION

Ambulance safety has improved recently as more stringent test procedures have been developed. Recent work by the National Institute for Occupational Health and Safety (NIOSH) has been instrumental in defining new test procedures and educating ambulance manufacturers and designers on ways to develop safer structures, restraint systems, and interior furniture.

Vehicle crashes are the leading cause of death and serious injury among emergency service personnel [1]. Rollovers are among the leading crash types that result in serious injury and death to ambulance personnel and patients. Injury can be caused under rollover conditions either directly from interaction with intruding and crushing surfaces or indirectly by occupants being thrown around inside the module or by becoming ejected through failed doors and glazing. The damage to the module caused during a rollover, (e.g. stuck doors), can also hinder rescue efforts and delay treatment, which may exacerbate injury severity.

The NIOSH, the Department of Homeland Security's Science and Technology Directorate, and the Society of Automotive Engineers (SAE) developed recommended and standardized testing practices for evaluating the rollover crashworthiness, among other safety performance tests, for ambulance modules. The current Ambulance Modular Body Evaluation Recommended Practice (SAE J3057) was issued in 2017 [2]. The protocol for the dynamic loading event was developed based on the accelerations and forces measured from rollover tests of exemplar ambulances using three test methods: corkscrew, tip up (ECE R66), and dolly rollover (FMVSS 208).

The SAE J3057 test procedure is a two-phased protocol for the modular body compartment, which includes an initial dynamic impact followed by quasi-static loading.

1. First, the ambulance module with chassis attached, is connected to a rigid steel test fixture at 20 degrees of roll. The module is attached to simulated frame rails (I-beams) which is bolted at 4 locations to the rigid test fixture. The stationary module is then impacted with a 6427 kg (14170 lb) cart with rigid platen traveling at 3.44 m/s (7.69

mph) to achieve an impact energy of 37.96 kJ (28,000 ft-lbf). The test setup can be seen in Figure 1. While the module-to-chassis attachments may deform or fail, the module must remain attached to the chassis in at least one location.

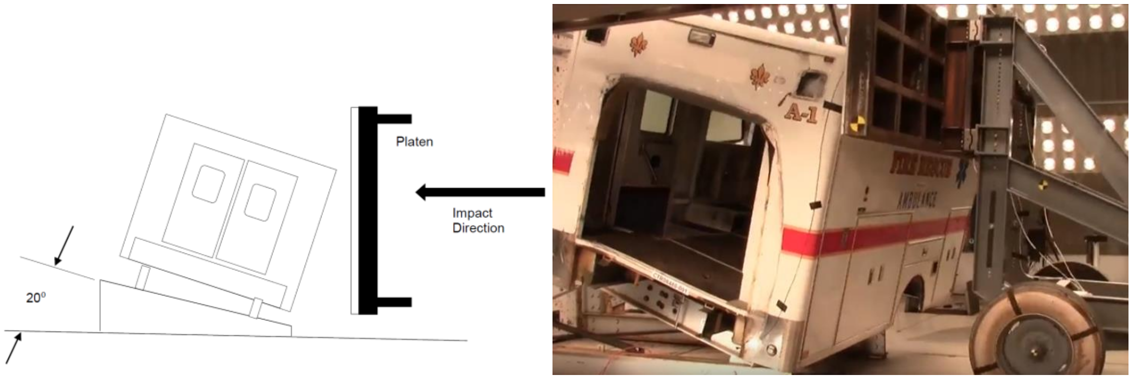

Figure 1. Test setup diagram (left) and impact between platen and ambulance module during a SAE J3057 test. Image taken from NIOSH online video series.

2. The module is then quasi-statically loaded in two orientations (upright and side). The doors of the module are required to open during application of peak force and after completion of testing.

METHODS

A LS-DYNA finite element model representing a current production ambulance body module was generated. The ambulance module model was attached to a modified National Crash Analysis Center (NCAC) model of a Ford E-Series cab and chassis (Figure 2). The model of the module contained only the components deemed to be structural.

Figure 2. LS-Dyna Model of Production Ambulance

The model was subjected to the specified SAE J3057 dynamic impact test and the SAE J3057 with modified constraints and boundary conditions. The quasi-static phase of the SAE J3057 test was not simulated. For each test the ambulance was positioned with a 20-degree roll angle, 0-degree pitch angle, and 90-degree yaw angle relative to the impactor or ground surface. Table 1 summarizes the simulation parameters in each model.

Table 1. Simulation Parameters

Test ID	Constraint	Impact Speed (m/s) [indicates velocity normal to ground surface]	Impact type
Standard	Standard	3.44	Cart/Platen
Mod_1	Horizontal	3.44	Cart/Platen
Mod_2	Unconstrained	3.44	Cart/Platen
Free_1	Free	3.44 [1.18]	Ground load
Free_2	Free	8.94 [3.06]	Ground load
Free_3	Free	13.41 [4.59]	Ground load

The constraint types used in the study included the following:

1) Standard SAE J3057. Module rails clamped to chassis frame rails. Frame rails bolted to rigid test fixture. Test fixture fully constrained.
2) Horizontal. Module rails clamped to chassis frame rails. Frame rails bolted to rigid test fixture. Test fixture allowed to move horizontally.
3) Unconstrained. Module rails clamped to chassis frame rails. No constraints on motion. No test fixture used.
4) Free. Module clamped to chassis frame rails. Ambulance subjected to fully unconstrained rollover. No test fixture used.

Two different impact types were evaluated in the study and are summarized in Figure 3:

1) SAE J3057: A rigid 6427 kg (14170 lb) platen was used to impact the ambulance at a predetermined velocity.
2) Ground load: The ambulance was given an initial velocity into a stationary rigid ground surface (rigidwall). An initial roll rate of 90 deg/s was also applied.

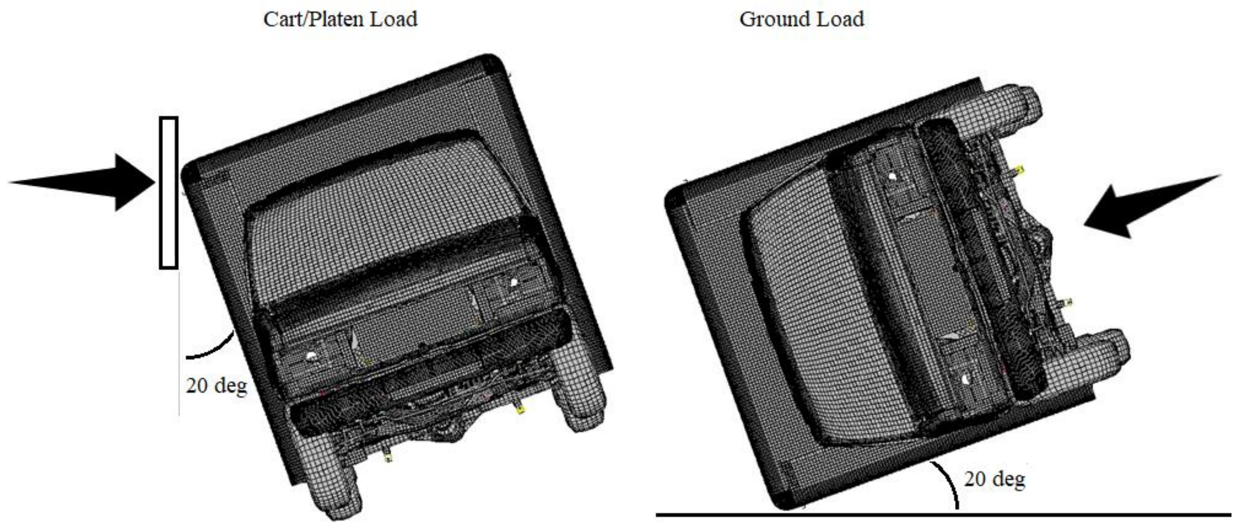

Figure 3. Finite Element simulation setup for Cart/Platen loading (left) and Ground Loading scenarios. The arrows indicate the direction of initial Cart/Platen or Vehicle velocity.

The response measures analyzed in this work included the impact force and the modular body distortion. The impact forces were measured as the contact force between the platen and the modular body or between the modular body and the ground surface. The modular body distortion was measured as the average change in distance between the impacted roof rail and the opposite chassis frame rail. All impact loads were filtered with SAE CFC 60.

RESULTS

Variations in test fixture constraints had no effect on the overall peak loads sustained by the module as demonstrated in Figure 3. The peak loads calculated under each of the three test fixture constraint methods were identical up to 20 ms. In each case the peak force was attained at approximately 8 ms after which the forces dropped rapidly. The J3057 test fixture method ('Standard') maintained a force level of approximately 20% of the peak force for over 200 ms while the lesser constrained methods produced little or no force after 60 ms. Figure 4 shows that the measured module distortion followed the force trend. The Standard method produced a steadily increasing level of deformation with a maximum deformation of 102 mm. The lesser constrained methods resulted in a maximum dynamic deformation equal to half that produced under the Standard method.

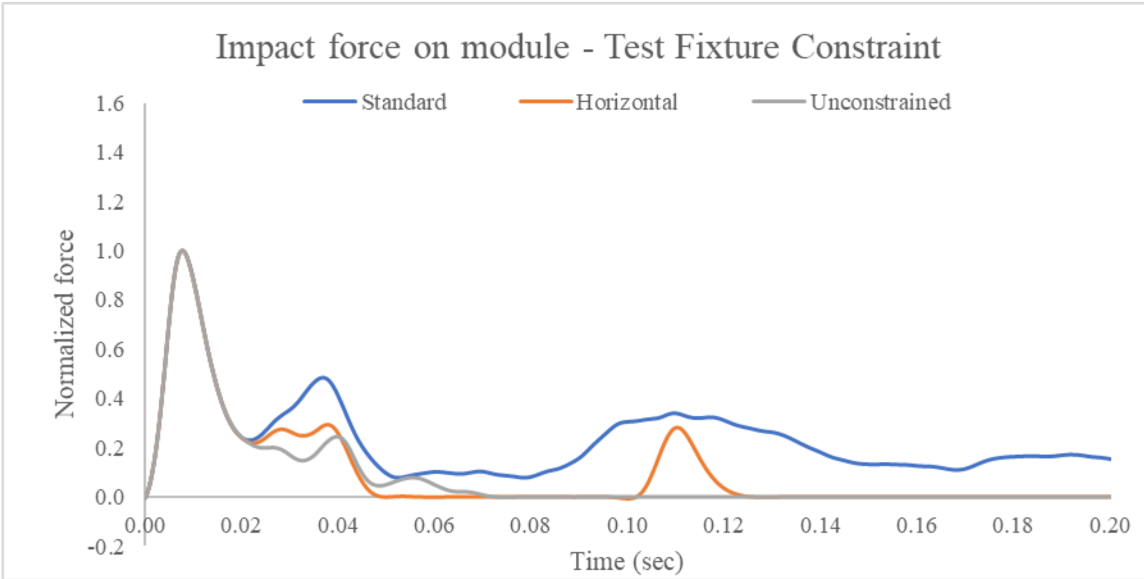

Figure 3. Impact loads under differing test fixture constraints.

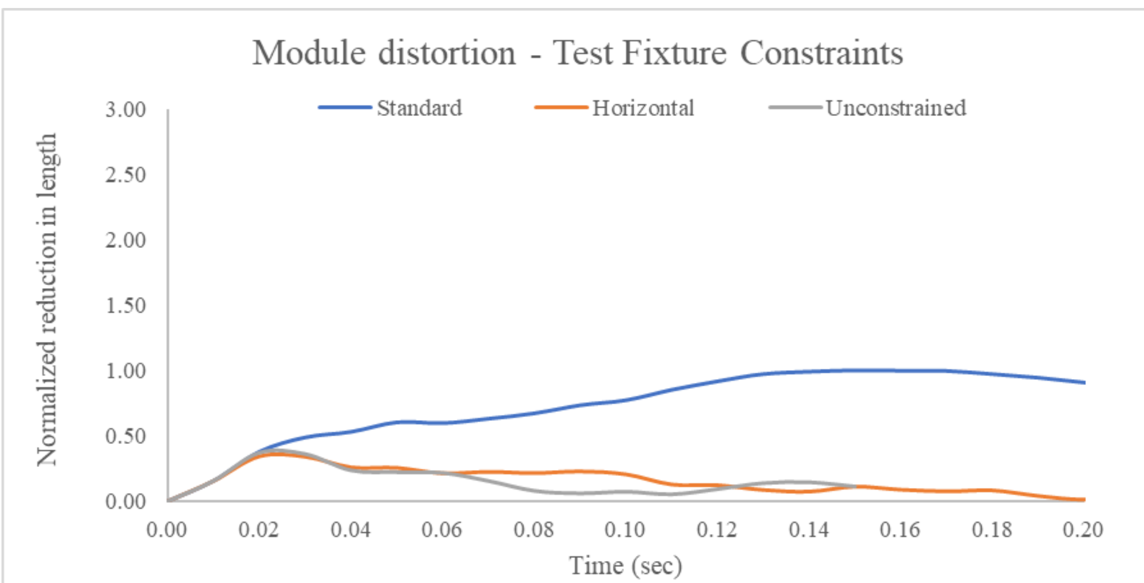

Figure 4. Module distortion measurements under differing test fixture constraints.

Figure 5 shows that the unconstrained rollover impacts produced impact forces up to 1.5 times greater than that produced under the Standard method. As the over-the-ground speed of the rollover increased, so did the impact force. The test configuration produced impact forces with a magnitude roughly between those produced by the rollovers with over-the-ground speeds of 3.44 m/s [7.7 mph] and 8.94 m/s [20 mph]. The measured module deformation echoed the force levels with greater impact speeds resulting in greater levels of deformation.

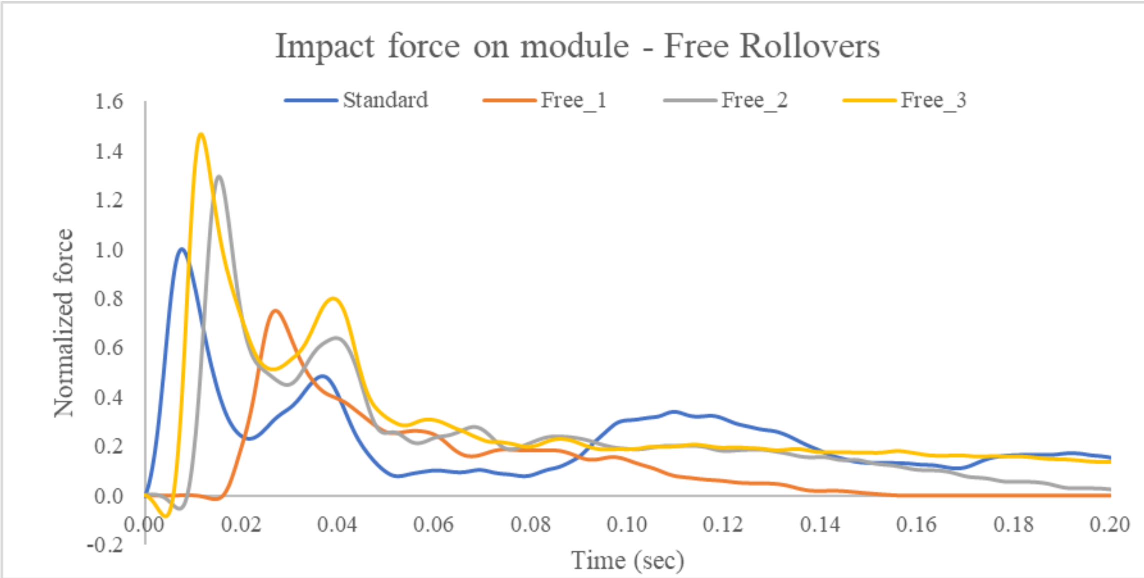

Figure 5. Impact loads under differing impact and rollover conditions.

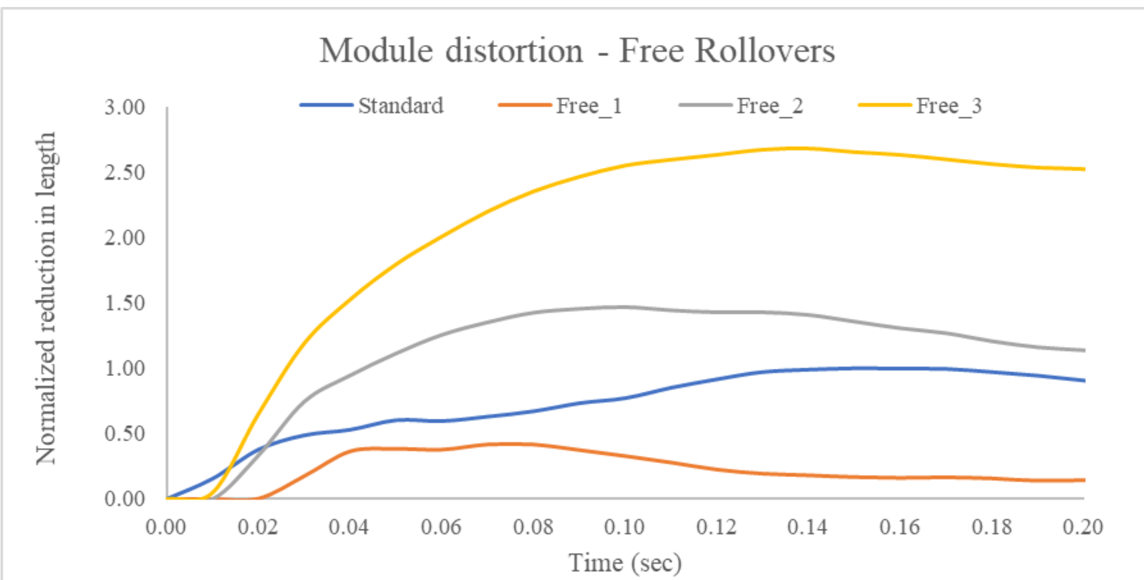

Figure 6. Figure 4. Module distortion measurements under differing impact and rollover conditions.

DISCUSSION

The updated recommended test procedures for ambulance module structural integrity will likely improve the rollover performance of ambulances. This work has shown, however, that the loading environment produced by this test procedure is roughly equivalent to a 6.2 m/s (13.8 mph) lateral rollover. This work also demonstrates that the J3057 constraint method produces a worst-case scenario for a given impact energy compared to other methods that may be feasible.

The current contraint method is also the most likely to produce repeatable results and the easiest to implement in a laboratory setting.

One common point of discussion among manufacturers regarding this test is the performance requirement of the module-to-frame connection. While the performance of these components was outside the scope of this study, further work will investigate the effects of test conditions and real-world rollover conditions on these parts. The J3057 requirement to attach the module to rigid frame rails instead of the original truck chassis frame rails likely results in a more agressive impact scenario since some of the compliance of that connection is removed. Further work will also investigate the need for the requirement to maintain a connection between the module and frame rails and how it affects the risk of injury in a rollover crash.

This work demonstrates a Finite Element analysis method that could support the design of an ambulance module to meet the requirements of the J3057. FE analysis could also support the design of module-to-chassis attachment devices.

REFERENCES

[1] B J Maguire, K L Hunting, G S Smith and N R Levick, ‘Occupational fatalities in emergency medical services: A hidden crisis’, Annals of Emergency Medicine, 2002, 40(6) 625-632.

[2] Society of Automotive Engineers, Surface Vehicle Recommended Practice J3057 ‘Ambulance Modular Body Evaluation-Quasi-Static Loading for Type I and Type III Modular Ambulance Bodies’, February 2017.