

Occupant Rollover Protection in Motorsports

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ABSTRACT

Over the last twenty years, large improvements in occupant safety have been made in NASCAR®'s (National Association for Stock Car Auto Racing, Inc) racing series. While proper occupant protection requires both occupant restraint and preservation of sufficient occupant survival space, this study is focused mainly on the latter of these two necessities. The NASCAR tubular vehicle chassis has evolved through the years to provide improved protection for the driver in rollover incidents. The chassis has continued to progress over time to improve its strength as unique crashes sometimes highlighted opportunities for advancement. Recent enhancements tested using computer modeling, quasi-static testing, and full scale drop tests have improved the roof structure of the stock car chassis. These improvements have been incorporated into the 2013 NASCAR Sprint Cup and Nationwide Series cars.

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INTRODUCTION

Successful occupant protection requires two main principles. First, the occupant must be properly restrained. Proper restraint couples the occupant to the restraint system as early as possible in the event, limits occupant motion to prevent both injurious contact with the vehicle interior and injurious kinematics, and distributes restraint loads across appropriate load bearing regions of the body. In NASCAR this restraint system consists of a minimum 6-point seat belt restraint system, head and neck restraint, helmet and containment seat. The development and role of these pieces of safety equipment has been detailed in other publications [1,2,3,4,5].

Secondly, an occupant must be given sufficient survival space within a vehicle. An envelope free from intrusion around the occupant must be maintained throughout a crash and must account for the kinematics of the occupant, which are dictated by the restraint system, input acceleration and direction and occupant size. A quick search of the literature will show how human tolerance to rapidly applied accelerations has been increased with restraint system improvements over the last 70 years. However, human tolerance to contact induced injuries such as crushing and high speed impact with rigid structure remains largely unchanged and low.

Both of these principles must be present and achieved for successful occupant protection.

SAE (Society of Automotive Engineers) Technical Publication 2011-01-1105 presented a brief historical progression of the NASCAR tubular roll cage [6]. The majority of the NASCAR Sprint Cup and Nationwide chassis is made up from round magnetic steel seamless tubing 1.75 inch outside diameter by 0.090 inches minimum wall thickness meeting the ASTM A-519 specification [7]. For the 2013 racing season, two additional pieces of this tubing will be required in the chassis, providing increased roof structure strength.

While rollovers do not represent a significant percentage of the on-track incidents in NASCAR, they do occur. Most rollover incidents, while visually impressive, do not create the magnitudes of acceleration that other vehicle impact orientations do. Rollover events tend to occur over much longer durations of time, providing more opportunities to disburse kinetic energy. There are however, potential orientations of roof impact which combine elevated magnitudes of acceleration with the least initial available occupant survival space. This impact orientation was the focus of the testing and structural improvements presented in this paper. Generally, this orientation is representative of a vertical impact to the driver's side A-pillar of the vehicle.

While the 2012 and previous NASCAR chassis' provided excellent protection during rollover incidents, an opportunity for safety improvement was identified, pursued and implemented.

DISCUSSION

Rollover Incident Case Study

Each NASCAR National Touring Series race vehicle carries an onboard Incident Data Recorder (IDR) during NASCAR sanctioned events. The IDR records tri-axial acceleration of the chassis and is rigidly mounted on the left frame rail, adjacent to the driver. The IDR has programmable acceleration and time duration trigger thresholds for each individual axis. This tuning capability is necessary to discriminate against nuisance events. For example, during a pit stop, a NASCAR vehicle may experience 10 G of acceleration in the vertical direction when it lands from a jack during a tire change. Large vertical accelerations are also commonly seen when the race vehicle chassis contacts the racing surface during hard cornering or braking. It is desirable that these input accelerations be ignored by the IDR.

However, a balance exists between optimizing against nuisance IDR recordings and desensitizing the vertical axis to an extent of not recording the initial phase of a rollover event. A solution to this issue was realized by extending the event record time of the IDR to twenty seconds. Each time the IDR is triggered it records for twenty seconds. During normal download procedures, only the first two seconds of data is transmitted to the computer. In the case of a rollover, or other unique circumstance, like multiple impacts, the full twenty seconds of data may be accessed and analyzed. This solution has proven effective, as rollovers in NASCAR are often precipitated by contact which exceeds the lateral and longitudinal trigger thresholds, thus starting the recording process. A more in depth review of the NASCAR IDR is presented in the SAE Technical Paper 2011-01-1103 [8].

Figure one shows an example of the acceleration versus time plot of a NASCAR vehicle during a rollover event. The gaps in the data are due to a 1.5 second record time. The IDR re-triggered each time the trigger threshold was exceeded. This event was captured before the twenty second record time was implemented. This vehicle came to rest on its roof after 3.5 rolls. The driver of the vehicle self-extricated and ambulated to the ambulance after the vehicle was righted by a prescribed maneuver initiated by the NASCAR Track Services Team. The driver suffered no injuries, was evaluated and released to return to racing.

Figure two shows a close up of the 42.8 to 44.4 seconds of the case study event. The resultant x, y, z acceleration (R) is shown in black and the resultant change in velocity (R ΔV) is shown in gray on the secondary vertical graph axis. Care must be taken when analyzing the resultant acceleration and R ΔV due to the changing axis acceleration offsets present as the vehicle rolled. The overall magnitude of the R ΔV may not be relied upon, as the offsets in between impacts continually add to it. It is however representative of the magnitude of R ΔV experienced for each individual impact shown in Figure two.

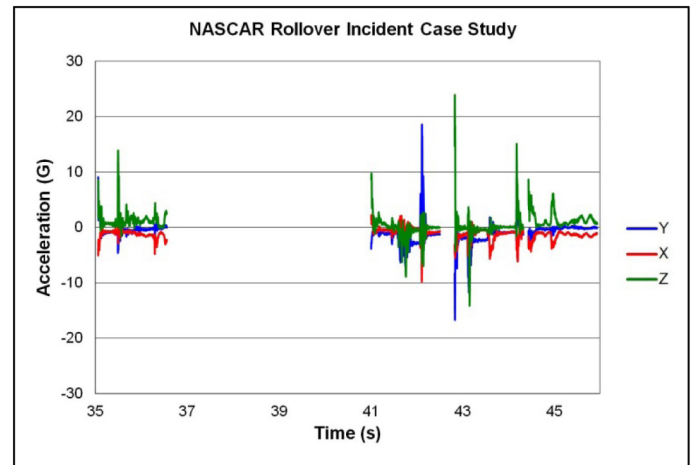


Figure 1.

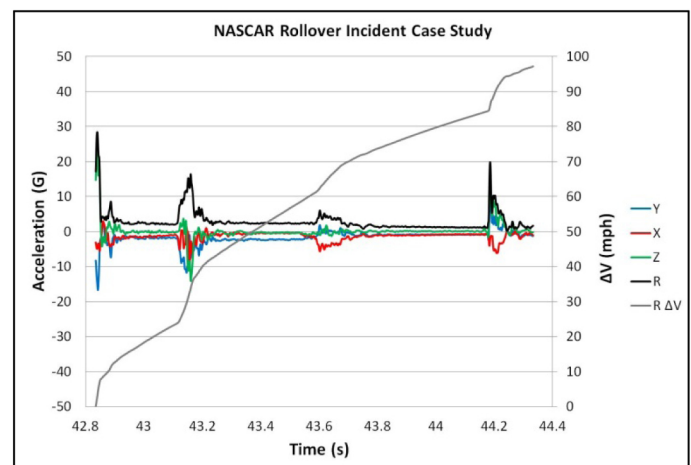


Figure 2.

Roof Structure Quasi-Static Testing

Quasi-static testing of vehicle roof structures is an accepted and reliable method for establishing the quasi-static stiffness or strength of a roof structure assembly. Quasi-static loading of the driver's side roof structure was conducted. The left and right main frame rails were rigidly secured to the test surface with the horizontal shoulder bar (#7) of the chassis oriented to 25° from vertical. The chassis was also rotated counterclockwise, when viewed from above, to form a parallel plane of contact (the red vertical line in Figure 3) with the load wall between the crown of the roof bar (#3) and the front roll bar leg (#2A) and dash panel bar (#8) junction. This testing orientation is shown in Figure three.

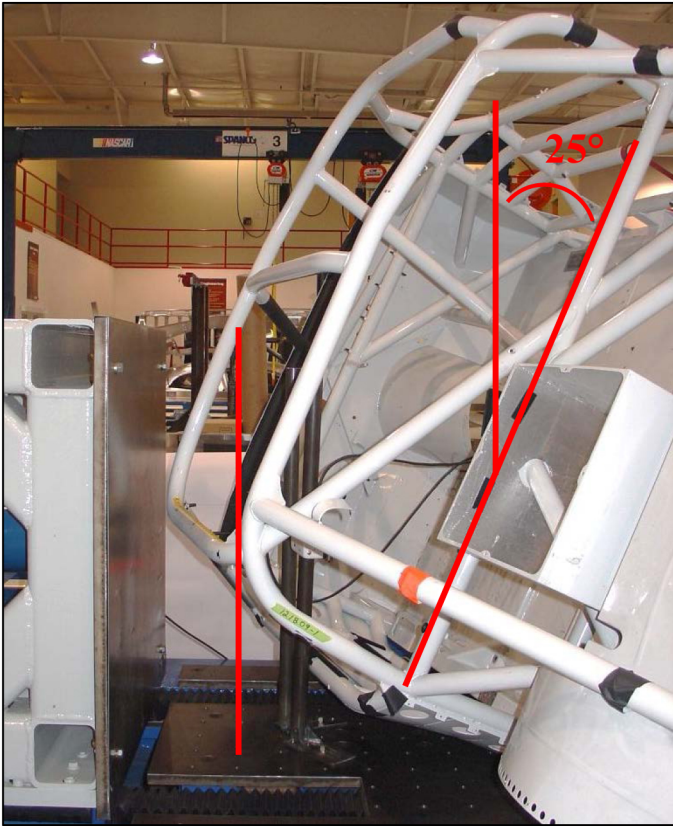


Figure 3.

The load wall is on the left in [Figure three](#) and translated into the chassis at a constant rate of 0.2 inches per second. Force and deflection data was acquired at 100 samples per second which is shown in [Figure four](#). Pictures of the baseline chassis test and alternative designs are shown in [Appendix A](#).

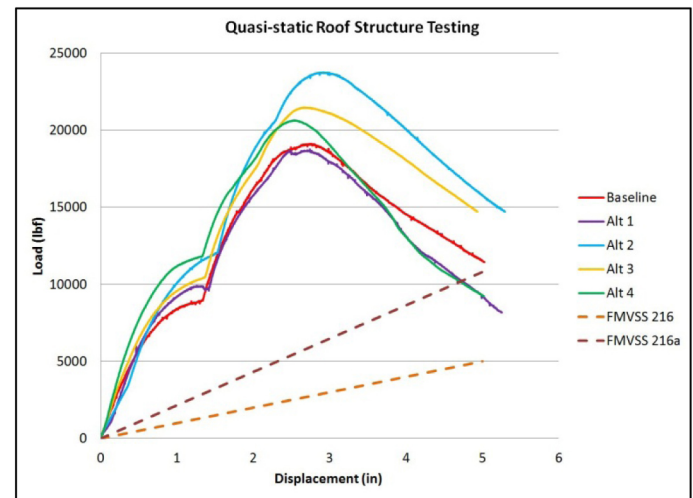


Figure 5.

As shown in [Figure five](#), the baseline (2012 and previous) NASCAR Sprint Cup chassis displayed a deflection of 0.42 inches at 5,016 lbf and at 10,818 lbf the deflection was 1.45 inches.

Roof Structure Computer Modeling

In addition to the quasi-static testing of the roof structure, non-linear finite element analysis was conducted on the chassis by Corvid Technologies. Specifically, a computer CAD model of the entire chassis was meshed, exercised and output data analyzed. The modeled chassis did not contain exterior sheet metal or suspension. Simplified masses were used for the engine and transmission. Additional ballast rails were added to the main frame rails to account for the missing components in the CAD model. The meshed model is shown in [Figure six](#).

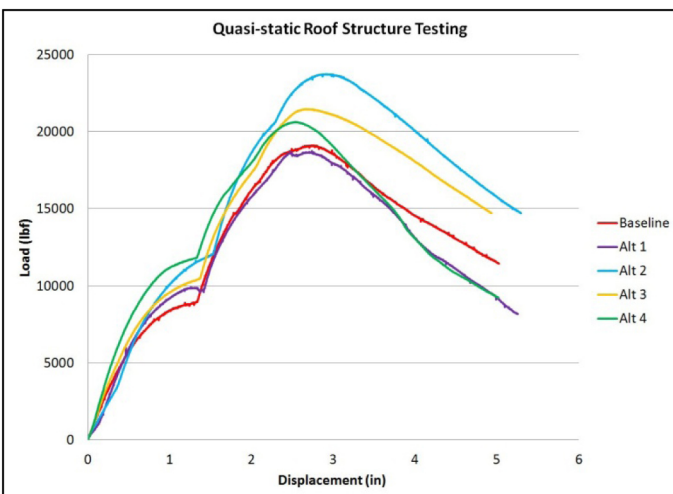


Figure 4.

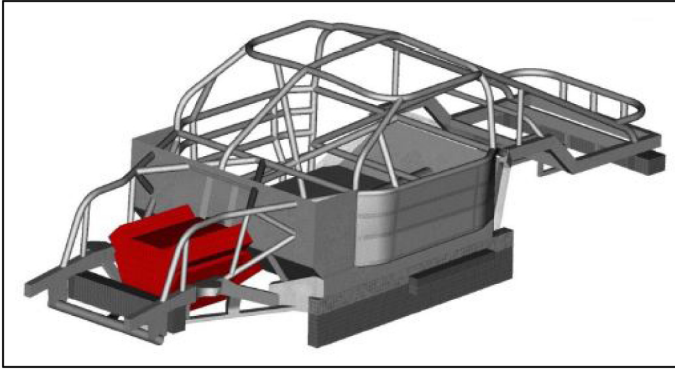


Figure 6.

In order to sufficiently validate the chassis simplifications made for the model, a full scale drop test was conducted with the same simplifications, which is shown in [Figure eight](#). [Table one](#) shows a comparison for mass and center of gravity (CG) of the NASCAR test car to the Model.

Table 1.

		Model	NASCAR
Mass (lb)	Roll Cage	600	598
	Engine	481	480
	Ballast	2459	2463
	Total	3540	3541
CG (in)	X	30.42	32.60
	Y	28.83	28.80
	Z	3.64	2.60

[Figure seven](#) shows the model simulation orientation.

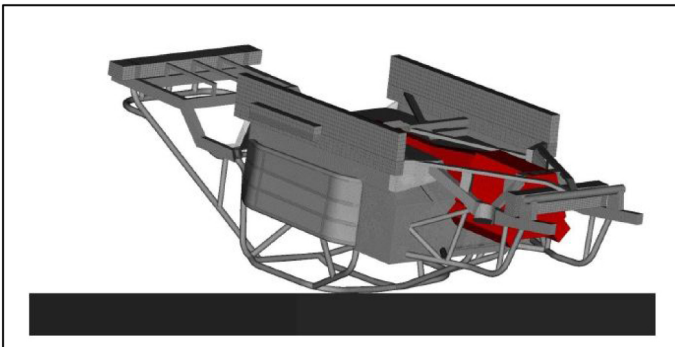


Figure 7.

[Figure eight](#) shows the validation drop test orientation. The drop test vehicle and simulation were setup with an 18° nose down and 10° driver's side down orientation. This produced a plane of contact with the ground across the driver's side A-pillar. More detailed information about the drop test setup is discussed in the Roof Structure Drop Testing section.



Figure 8.

After several model iterations and adjustments the simulation provided acceptable correlation to the actual test data. [Figures nine](#) and [ten](#) show examples of the simulation to drop test correlation.

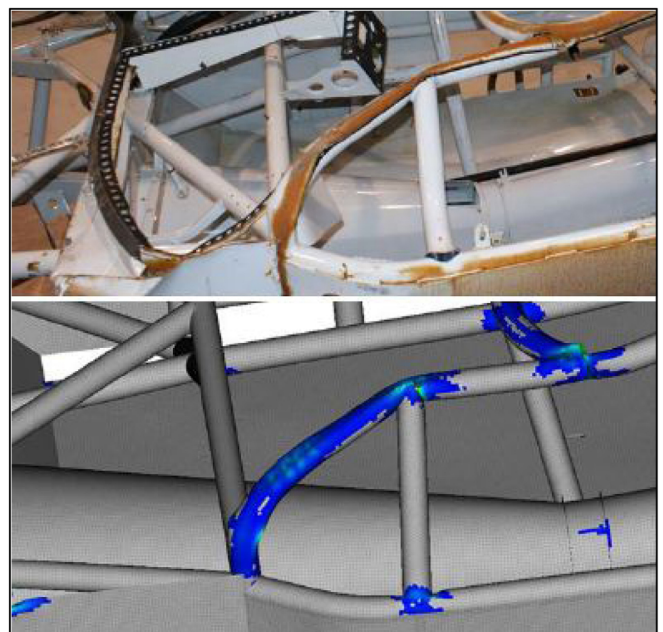


Figure 9. Documents
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