EFFECT OF FMVSS 226 COMPLIANT CURTAIN AIRBAGS ON THE BRIC RESULT OF A HYBRID III 50TH% DUMMY DURING AN OBLIQUE IMPACT

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ABSTRACT

The proposed oblique impact test with a Research Moving Deformable Barrier (RMDB) by the National Highway Traffic Safety Administration (NHTSA) is designed to represent crashes involving partial longitudinal structural engagement between vehicles. The RMDB moves at a speed of 56mph (90kph), with a small overlap of 35% and an impact angle of 15°, into a stationary vehicle. In addition, the newly developed Test Device for Human Occupant Restraint (THOR) dummy and the Brain Injury Criterion (BrIC) are used to evaluate the injury risk. The implementation of these test modes and measurement techniques will raise the bar for performance of passive safety systems.

Meanwhile, the introduction of the Federal Motor Vehicle Safety Standard 226 (FMVSS 226) as a countermeasure for ejection mitigation during a rollover has increased the occupant protection area of side curtain airbags (SCAB). As a result, SCAB designs have incorporated increases in height, width, and depth, depending on the interaction of the airbag with the vehicle's interior. This dimensional change in FMVSS 226 compliant SCAB, while yielding positive results in side impact and rollover crashes, may also play a critical role in the prevention of injury for the NHTSA oblique test mode. This study examines the effect of the expanded occupant protection coverage of FMVSS 226 compliant SCAB on BrIC results during an oblique impact.

This study used publicly available oblique pulse data (published by NHTSA) in a Finite Element (FE) model with a Hybrid III 50th% dummy to perform an oblique impact test. The interior environment of the FE model was obtained by digitizing a generic buck and morphing available FE models from the National Crash Analysis Center (NCAC) database. The FE model was validated with a belted 35mph frontal impact test (FMVSS 208) and then used for the oblique impact analysis. This study examines three oblique FE models, each consisting of a different configuration of restraint systems. The first configuration did not utilize a SCAB; the second configuration had a non-FMVSS 226 compliant SCAB; and the third configuration had a FMVSS 226 compliant SCAB. In order to assess the effect of SCAB design, only the upper body results of the dummy were compared and analyzed. Differences in injury response were observed between the three configurations when evaluating the head acceleration, head rotation, and chest deflection. A significant improvement was observed in the BrIC result for the FMVSS 226 compliant SCAB when compared with the other two restraint system configurations tested. Though this study is design-specific, appropriate explanations are provided to support the study.

INTRODUCTION

Despite continuous improvement to passive restraint systems, serious injuries and fatalities still occur during a crash event, even when all restraint systems operate as designed. Recently, oblique vehicle-to-vehicle impacts have been identified as a high risk scenario for occupants by the National Highway Traffic Safety Administration (NHTSA), and further supported by Rudd *et al*, [2011][1], wherein the vehicle's longitudinal structural members are only partially engaged. NHTSA has developed a test procedure to address this crash mode, refining the criteria for an oblique test method as a 35% overlap, at an angle of 15° (345 Degrees PDOF), impacting a stationary vehicle with a newly developed (Research Moving Deformable Barrier) RMDB that travels at 56mph (90kph)[2]. This test mode has introduced new challenges in occupant safety system design, as the resulting kinematics cause limited engagement of the frontal and side restraint systems by the occupant. This has led to an increased focus in the automotive industry on the protection of the occupant by the side and curtain airbags during these types of crash modes.

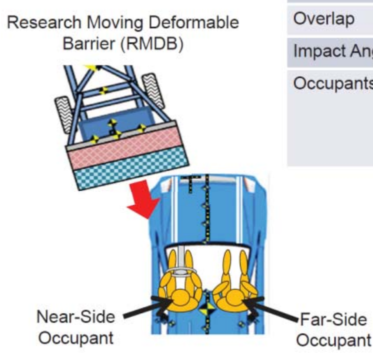
Early research of the occupant kinematics and resulting injury modes in the oblique condition led to the creation of the Brain Injury Criterion (BrIC), presented in its most current form by Takhounts *et al.* [2013][3]. The BrIC is measured using the X-, Y-, and Z-axis angular velocities of the head, and is intended to capture the risk of brain injuries as a supplement to the translational acceleration measurement used to calculate the Head Injury Criterion (HIC). Due to the occupant kinematics found in oblique crash conditions, a high level of head and torso rotation and excursion may result, making BrIC a critical measurement for establishing safety system performance.

The FMVSS 226 test protocol was formally introduced in 2013 to prevent the ejection of occupants during a rollover crash, and has led to improved SCAB coverage in the X-, Y-, and Z-directions in-vehicle. This study will examine the effect of the utilization of an FMVSS 226 compliant side curtain airbag (SCAB) as it relates to occupant kinematics and BrIC results during an oblique test.

METHODS

Background

The newly developed NHTSA oblique test condition is specified as a Near-Side collision, wherein the RMDB impacts a stationary vehicle at 90kph, with a 35% overlap and an impact angle of 15° (Figure 1).



RMDB Speed	56 mph (90 kph)	
Overlap	35 percent	
Impact Angle	15 degrees (PDOF = 345)	
Occupants	Near-side (Driver)	THOR Mod Kit 50th Male
	Far-side (Passenger)	THOR Mod Kit 50th Male

Figure 1. NHTSA Oblique RMDB Test Configuration.

Previous research has found that the new NHTSA oblique test mode introduces an increase in injury risk primarily to the Head, Chest, and Lower Legs, due to the angle of impact and intrusion levels observed in testing[4]. BrIC is a recently established head injury metric developed by Takhounts *et al.* [2013] which uses the maximum angular velocity (ω) measured about the X-, Y-, and Z-axes to determine the risk of injury to the brain due to rotational velocity of the head. For this study, BrIC was calculated using the equation in Figure 2.

Critical Angular Velocity	Rad/s
ω_{xC}	66.25
ω_{yC}	56.45
ω_{zC}	42.87

Where ω_x, ω_y, and ω_z are maximum angular velocities about X-, Y-, and Z-axes respectively, and ω_{xC}, ω_{yC}, and ω_{zC} are the critical angular velocities in their respective directions.

$$BrIC = \sqrt{\left(\frac{\omega_x}{\omega_{xC}}\right)^2 + \left(\frac{\omega_y}{\omega_{yC}}\right)^2 + \left(\frac{\omega_z}{\omega_{zC}}\right)^2}$$

Figure 2. BrIC Calculation based on Takhounts *et al* [2013].

This study is concerned with the design and presence of installed SCABs, and their effect on both the BrIC value, and the overall reduction in head rotation.

Model Development and Validation

Before developing an oblique test method in computer-aided engineering (CAE), dummy kinematics and injury performance for an NCAP frontal crash were examined and validated using data from (3) developmental sled tests performed in-house. In order to correlate with the frontal NCAP sled testing, a Hybrid III dummy was used in the CAE environment.

For the frontal model validation, safety system components were chosen to match those used in the developmental sled program, and demonstrated good stability. The components used included a driver airbag (DAB), knee bolster airbag (KAB), and a 3-point seatbelt utilizing a pre-tensioner and load limiter. Simulations were then performed in CAE using the acceleration data used in the sled environment, and the results were analyzed. Upon reviewing the results, the CAE tests showed good correlation in Head, Chest, and Pelvis acceleration in both magnitude and phase, while Chest Deflection showed good correlation during loading, but exhibited a shorter duration than was observed on sled. Femur force was measured for both left and right femurs, and while the right femur showed good correlation to NCAP sled test data, the left femur exhibited higher magnitude and duration of loading than the physical tests (Figure 3). After evaluating the injury response by the upper body, it was decided to move forward with development of an oblique test setup in CAE, as the correlation to physical sled testing for occupant response in a frontal impact was good.

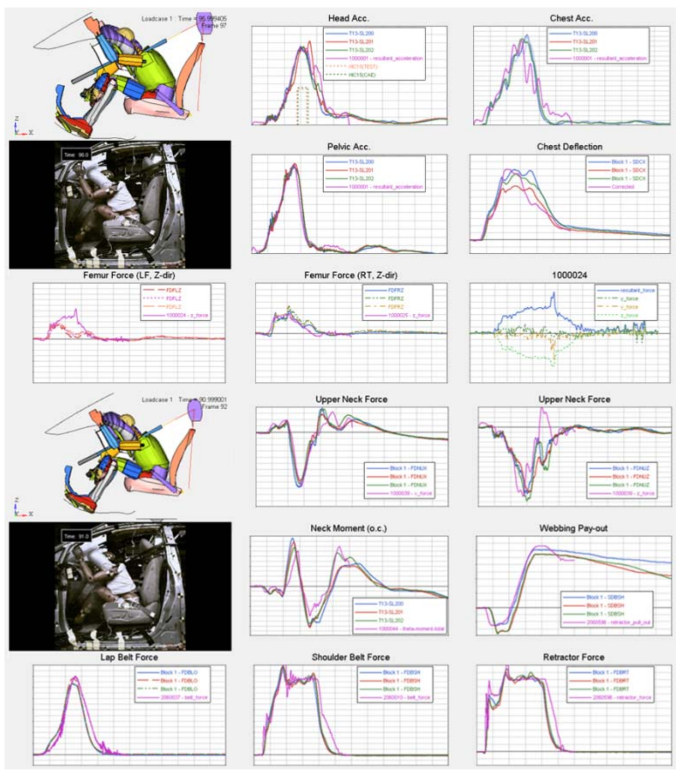


Figure 3. Frontal Impact Validation with Sled Series.

Three test conditions were chosen for examination of the SCAB effect on occupant kinematics in the oblique test condition. The first condition consisted of running the simulation with no SCAB present, utilizing only the DAB, KAB, and a pre-tensioning seatbelt with load limiter. In order to examine the benefit of an FMVSS 226 compliant SCAB, two SCAB models were used for the two subsequent tests. The first SCAB was a non-FMVSS 226 compliant, 2-row airbag, with a 50L capacity and an inflator whose output was 230kPA. Meanwhile, the FMVSS 226 compliant SCAB that was used in this experiment had a volume of 62L, and an inflator output of 350kPa. In the FMVSS 226 compliant SCAB, additional cells were added (Figure 4), and the airbag coverage was expanded in both the X- and Y-directions, relative to the vehicle coordinate system.

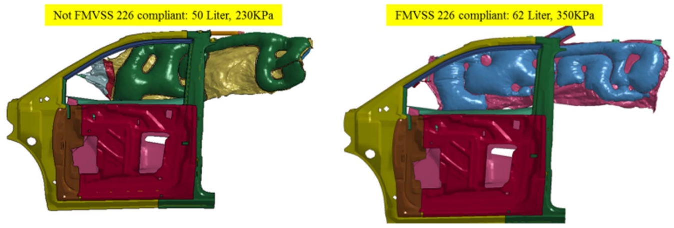


Figure 4. Comparison of Non-FMVSS 226 compliant, and FMVSS 226 compliant SCAB.

In order to establish an oblique acceleration to be used in the CAE model, a desktop review of NHTSA-published oblique pulse data was performed in order to find a pulse representing a stiff vehicle response. The acceleration data from the NHTSA database was selected[5], and the X- and Y-direction accelerations were input into CAE, with an impact location at the front left corner of the vehicle. This allowed the model to experience the same vector of acceleration as the NHTSA test, without incorporating vehicle rotation into the study.
A Hybrid III 50th% male dummy was used for the CAE oblique testing. The Hybrid III exhibits a slightly different kinematic response and lower injury values than the THOR in physical testing when a significant vehicle Y-displacement is observed[6]. However, the Hybrid III model is very stable, and since the physical dummies are readily available, CAE oblique test results could be more easily confirmed at a later time through sled testing. The dummy was positioned using the setup numbers from the frontal sled tests, providing a uniform starting point for each simulation. SCAB modeling utilized a roll fold, and was then inflated at a time-to-fire (TTF) consistent with the published data, using the corpuscular particle method available in LS-DYNA to achieve full and representative deployment.

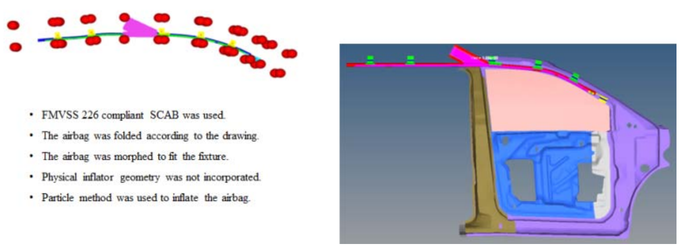


Figure 5. SCAB Morphing and Inflation.

Once the variables for the simulation were set, tests were performed for each of the three SCAB conditions, and results were compared.

RESULTS

The simulation results for the SCAB performance and occupant behavior are presented and discussed below. Each of the three conditions simulated created marked differences in occupant kinematics as well as occupant injury response. The BrIC value, which is the injury factor of interest in this study, is evaluated in relation to the presence and design of the SCAB for each simulation.

Occupant Kinematics
For all three CAE simulations, the occupant exhibited forward and outboard movement consistent with that found during NHTSA oblique testing. The overall occupant kinematics were very similar in each test, as the seatbelt response was consistent throughout the experiment. However, in the absence of the SCAB, the occupant's head showed the greatest lateral movement of any configuration, as the head was unrestrained in its movement in the Y-direction (Figure 6).

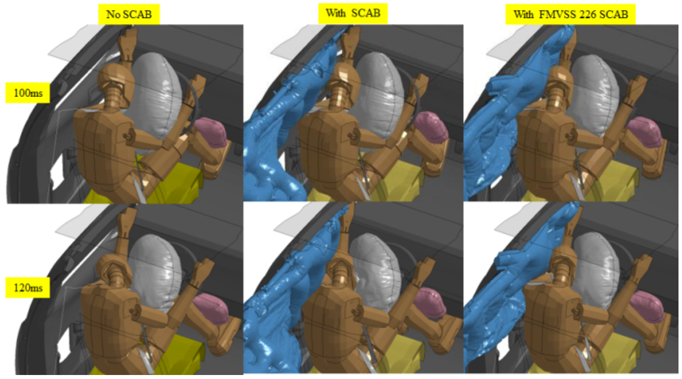


Figure 6. Simulation Results - Occupant Kinematics Comparison.

The head angular velocities for CAE were compared to the published data for the NHTSA oblique test[5] (Figure 7). The magnitude of the velocity for each direction of rotation was exhibited slight differences, but the location and timing of each peak were consistent between CAE results and the published data. This comparison demonstrated that kinematically, the CAE model was representative of the motion seen by the occupants in the NHTSA oblique test method.

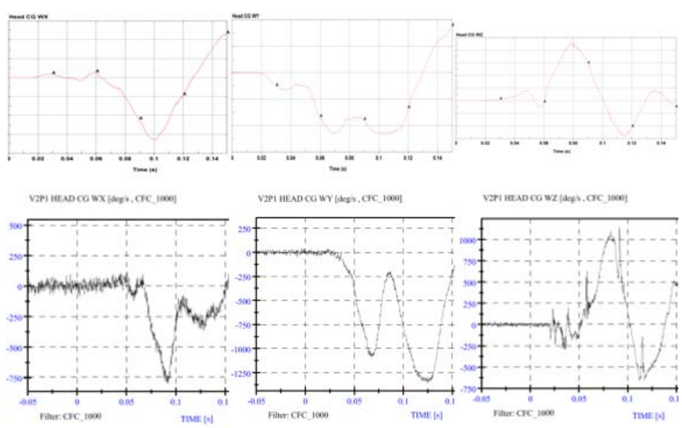


Figure 7. Head Angular Velocity - CAE vs NHTSA Results.

As seen in Figure 8, the increased chamber size in the Y-direction of the FMVSS 226 compliant SCAB creates contact with the occupant's head sooner in the crash event, limiting lateral movement and minimizing rotation. The early contact creates a counter- rotation effect that reduces the overall angular velocity for the event.

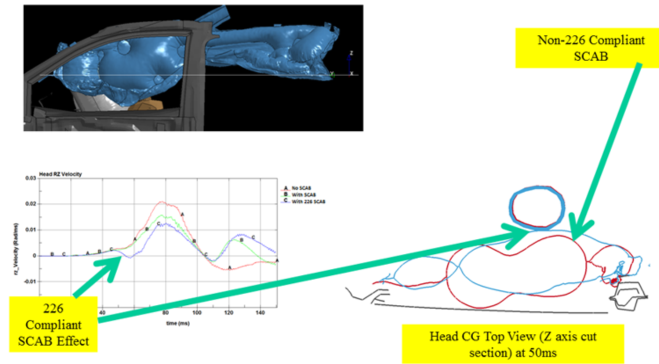


Figure 8. Head Rotation about Z-axis - 226 SCAB Reduction Effect.

BrIC Performance

In the baseline study, with no SCAB present in the simulation, the occupant exhibited forward and outboard movement. The DAB was contacted left-of-center, and the occupant's head proceeded to move outboard toward the door trim; however, the occupant's head made no contact with the door. The head experienced significant angular velocity about the X-axis (41.124 rad/s), as well as an elevated ω_z (21.163 rad/s), resulting in a BrIC score of 0.8725. Of the three CAE simulations, the baseline test resulted in the highest BrIC score.

The second test incorporated a SCAB into the safety system design, yielding changes in the kinematics of the occupant. In this simulation, the occupant trajectory was similar to the baseline study; however the presence of the SCAB guided the head during forward movement, reducing the ω_z to 15.931 rad/s, while the ω_x result (41.552 rad/s) matched the baseline, and a reduction of 5.517 rad/s was seen in ω_y. The BrIC score for the second simulation was 0.8647.

In the final simulation, a change in occupant head kinematics was observed during interaction with the DAB and SCAB. The FMVSS 226 SCAB contacts the occupant's head earlier in the crash event, inducing a counter-rotation that limits the magnitude of the peak angular velocity (Figure 8). As a result, ω_z was reduced to 12.772 rad/s, the lowest of all three of the simulations, while ω_x saw a reduction as well, showing a peak angular velocity of 25.519 rad/s. These reductions in angular velocity resulted in the lowest BrIC score for all three scenarios, at 0.655, representing a 24.2% reduction in BrIC when compared to the non-FMVSS 226 compliant SCAB. The BrIC values for each test are shown in Figure 9 and Table A1 in Appendix A.

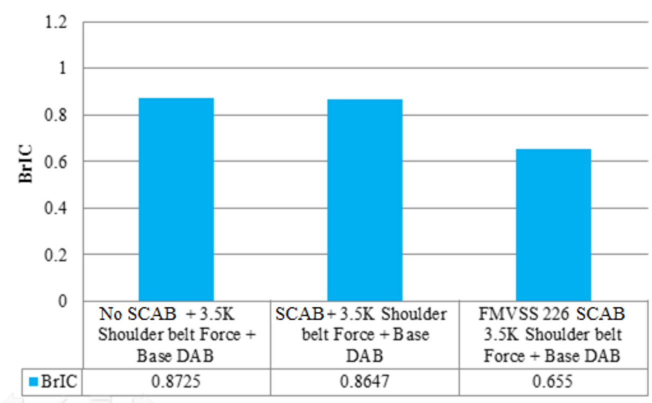


Figure 9. BrIC Review for SCAB Configurations.

Figure 10 shows the head angular velocity characteristics for each direction of rotation. Of note within this data is the reduction in magnitude of rotation about the X- and Z-axes for the FMVSS 226 compliant SCAB.

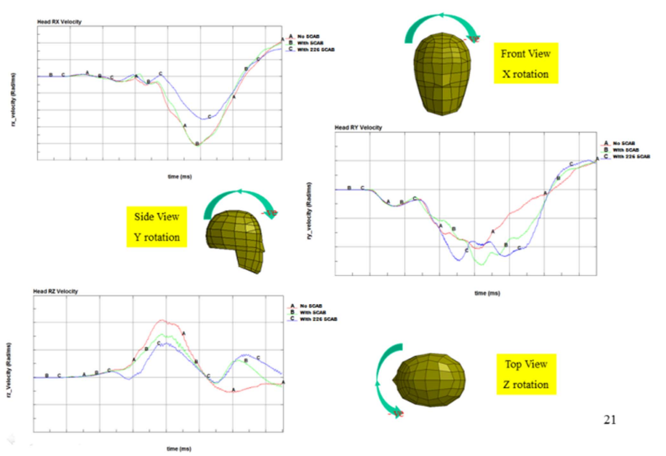


Figure 10. Head Angular Velocity Comparison.

CONCLUSIONS

This study has demonstrated that early engagement of a driver side occupant's head in an oblique impact using an FMVSS 226 compliant SCAB can reduce the rotation and angular velocity about the X- and Z-axes, thus reducing the overall BrIC score in a CAE test environment. This study acknowledges several limitations, including, but not limited to, the following:

- This study shows vehicle- and design-specific results using CAE. An analysis of a broad range of vehicle platforms and SCAB designs would be beneficial to reinforce the results reported herein.
- Using the Hybrid III CAE model may underrepresent injury risk in certain body regions. Additional CAE research using the THOR model may provide further insight into the effect of the FMVSS 226 compliant SCAB on BrIC.

Further CAE and sled testing is recommended to verify the performance of different FMVSS 226 compliant SCAB designs in different vehicle environments.

REFERENCES

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[5] National Highway Traffic Safety Administration, Vehicle Crash Test Database, Test No. 8097 (http://www-nrd.nhtsa.dot.gov/database/VSR/veh/VehicleInfo.aspx?LJC=8097)
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APPENDIX A

Angular Velocity (Rad/s)	No SCAB – CAE Result	With SCAB – CAE Result	With FMVSS 226 SCAB – CAE Result
ω_x	41.124	41.553	25.519
ω_y	20.539	26.253	24.784
ω_z	21.163	15.931	12.772
BrIC	0.8725	0.8647	0.655
HIC15	280.9	311.7	492.5

Table A1. BrIC & Angular Velocity Detailed Results.