Occupant Behavior and Brain Injury in NHTSA Oblique Test

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ABSTRACT

The National Highway Traffic Safety Administration (NHTSA) found that a large number of fatalities occurred in crashes involving poor structural interaction between the striking and the struck vehicles, such as corner impacts, oblique crashes, or impacts with narrow objects. NHTSA proposed the oblique test that can reproduce vehicle crush, occupant kinematics, and risk of injury in vehicle-to-vehicle crashes, an offset impact between a research moving deformable barrier (RMDB) and a stationary vehicle at a 15 degree angle.

Recent research for NHTSA oblique test with THOR ATD showed the lateral movement of both occupants, so that the driver’s head contact with door or between door and steering wheel. For the far-side occupant, the head contact with center IP and the brain injury risk predicted using BrIC is higher than SOI.

The objective of this paper is to investigate and understand the effect of airbag performance on the occupant kinematics and related injury during NHTSA oblique tests. This paper focuses on effect of various airbag parameters corresponding to the dynamic stiffness.

The research integrated the injury analysis with a crash testing and computer simulation. MADYMO was used to create a NHTSA oblique test environment. Both 50th percentile THOR ATD and Hybrid III in MADYMO were respectively used to simulate occupant kinematics and injuries for the driver and passenger occupant. Airbag models for curtain airbag and passenger airbag are used in the simulations in order to understand the effect of various restraint system concepts on occupant kinematics and injuries.

In this paper, driver side airbag and passenger side airbag are investigated for both near-side occupant and far-side occupant. CAE models are used to show their advantages and limitations. Further enhancements are proposed to improve the correlation of these occupant models. Passenger side airbag and driver side airbag are investigated to reduce the brain injury and head contact with compartment. NHTSA oblique test case is used to demonstrate the effectiveness of the airbag variations.

Limitations of the current airbag model used for NHTSA oblique test were highlighted. Vent hole was modified to improve the head injury. For reducing the brain injury risk of occupant in an NHTSA oblique test, it was found counter measures which didn't cause head rotation was effective.

INTRODUCTION

The past several years, most vehicles have achieved the good ratings in the IIHS frontal tests, and NHTSA’s frontal NCAP. This aroused the IIHS and NHTSA to investigate further test configurations for frontal impacts in order to improve the occupant safety. The Small Overlap Impact (SOI) test shown in Figure 1 has been introduced by IIHS, that is a 64 km/h frontal crash test in which 25% of the front-end of a vehicle is overlapped by a rigid barrier. The vehicle structural performance, restraints and dummy kinematics, and dummy injury measures are used to rate the vehicle’s overall safety performance as Good, Acceptable, Marginal or Poor. Four groups of dummy injury ratings utilize the instrumentation in the dummy’s head and neck, chest, hip and thigh, and legs and feet. The vehicle structural rating is based upon the pre-test and post-test measurements of seven various locations. Prior to the designing a NHTSA oblique test, shown in Figure 1, the NHTSA investigated fatal frontal crashes in the NASS database in which the occupants were belted non-ejected and the vehicles were equipped with frontal airbags. A large number of fatalities occurred in crashes involving poor structural interaction between the striking and the
struck vehicles in the report published in 2009[1]. On the other hand, full-frontal or offset-frontal impacts with good structural interaction ended in less fatalities, unless the crashes were of extreme severity or the occupants were exceptionally vulnerable. As a result of the NHTSA study, the agency stated its intent to further analyze small overlap and oblique frontal crashes [2]. NHTSA had conducted a large number of frontal crash tests, and developed a moving deformable barrier crash test, shown in Figure 1. The "research" moving deformable barrier (RMDB) impacts the target vehicle at 90 kph (56 mph) and the stationary vehicle is positioned such that the angle between the RMDB and the vehicle is 15 degrees and the overlap is 35 percent on the driver side of the vehicle[3]. The RMDB’s mass is 2490.7 kg (5491 lb.).

The hybrid III frontal crash test dummy is developed at 1970’s and the development of an advanced frontal crash test dummy with improved biofidelity under frontal impact conditions and with expanded injury assessment capabilities is needed. Under these circumstances, in 2001 an advanced frontal crash test dummy THOR (Test Device for Human Occupant Restraint) - Alpha version was developed in the United States[4]. After the THOR Alpha, later upgraded to the THOR-NT in 2005. A modification package (“Mod Kit”) intended to enhance the biofidelity, repeatability, durability, and usability of the THOR was introduced in 2011 and installed as an upgrade kit on the NHTSA owned fleet of THOR-NT ATDs[5]. Recent research showed that THOR dummy injury measures are closer to those of the post mortem human surrogates (PMHS) than the Hybrid III. By continuous improvement of THOR dummy[6]. Comparing responses of the THOR and the Hybrid III with the same conditions, the upper body of the THOR moved forward more, compared to the Hybrid III, and the torsion about the z-axis was also larger than the Hybrid III. As a result, the head acceleration of the THOR and the Hybrid III showed different responses. NHTSA Oblique RMDB crash tests included an anthropomorphic test device (ATD) seated in the driver (near-side) and passenger(far-side) position. These ATDs are a 50th percentile male THOR. Due to the test configuration of NHTSA Oblique RMDB, both side occupants responses in NHTSA’s tests showed rotational head velocities and resulted in high risk of brain injury. Rotational motion of the head can cause the brain injury and rotational kinematics experienced by the head may cause axonal deformations large enough to induce their functional deficit[7].

OBJECTIVES

The objectives of this study are:

1. Estimate the CAE simulation method of the oblique RMDB test for correlation refer to the dummy kinematics and the brain injury comparison between CAE result and test data.
2. Compare the dummy injury responses between THOR and Hybrid III in Oblique RMDB tests.
3. Estimate the sensitivity of the brain injury to different parameters of airbag.
METHODOLOGY

A correlated NHTSA NCAP model was used to build a NHTSA oblique RMDB baseline model. Modeling method for RMDB occupant analysis was constructed using both deceleration method and rigid body motion method as shown in Figure 2. The deceleration method is commonly used modeling method for FMVSS208 and NHTSA NCAP. The rigid body motion method is constructed by using the test motion of the tested vehicle. Structural intrusion data was extracted from a full vehicle test. The vehicle intrusion at struck side during test was used to replicate the vehicle test and to correlate the low extremity injuries and dummy kinematics. Hybrid III 50th percentile dummy was used first as a driver and a passenger occupants in order to compare the injury responses of THOR and Hybrid III dummy. This model used driver side airbag, passenger side airbag, curtain airbag, retractor and pre-tensioner as a restraint system.

![Figure 2. Occupant Simulation Modeling Methods for RMDB.](image)

Both baseline models used for this study demonstrated good correlation with NHTSA Oblique RMDB test. Validation index is unique index for evaluating the injury correlation rating of CAE model. Validation indices for the deceleration method and the rigid body motion method are 89 and 90 points respectively. This means both modeling methods give the similar injury response in peak and phase. For NHTSA Oblique RMDB test condition, occupant kinematics of the rigid body motion method showed better correlation with the test. This occupant kinematic correlation is shown in Figure 3.

![Figure 3. Dummy Kinematics.](image)

With this correlated model using the rigid body motion method, further study was conducted in order to understand the injury trends and occupant kinematics with variation of parameters. The passenger side occupant kinematics of the rigid body motion method showed good correlation with the test in Figure 4.
RESULTS

This study evaluated the kinematic and the brain injury responses of a THOR and the 50th percentile Hybrid III in the NHTSA Oblique RMDB frontal impact condition. The 50th percentile Hybrid III dummy is replaced by the THOR in the baseline model and then compared with the test results and the injury tendency. It was observed from the CAE simulation result data that the brain injury of the THOR dummy tended to increase about 30~51% with respect to the Hybrid III dummy. Figure 5 compares injuries for THOR dummy and Hybrid III dummy. BrIC values were higher for THOR dummy in both driver and passenger. This increasing tendency of the brain injury is also observed in the tests. The differences of neck joints between THOR dummy and Hybrid III dummy caused the increasing of the BrIC.

Figure 4. Comparison of Passenger Dummy Kinematics between Test and Simulation.

Figure 5. BrIC Response of THOR and Hybrid III
The purpose of this parameter study was to understand the effectiveness of the restraint system based on airbag’s internal pressure. To achieve this, airbag’s outer vent was varied at every 5 mm step.

Figure 6 compares internal pressure and BrIC for various vent hole size. Outer vent hole size variation analysis showed that as internal pressure decreased, BrIC is increased. Head X travel and Y rotational velocity were increased with decrease in internal pressure level of DAB. Since DAB’s reaction force was reduced, it allowed dummy head and chest to travel farther increasing the dummy’s forward movement.

From the internal pressure analysis of PAB, it was observed that with decrease in internal pressure level of PAB, BrIC was decreased slightly. It was seen at the lowest level of BrIC for 60mm outer vent. The lower internal pressure result in decreasing Z rotational velocity of the passenger’s head.

**CONCLUSIONS**

1. For dummy injury response, there is slight difference between the deceleration method and the rigid body motion method. The rigid body motion method for CAE modeling gives better correlation in dummy kinematics with the test both driver side and passenger side occupants.
2. It was observed from CAE simulation result data that the brain injury of the THOR dummy tended to increase about 30~51% with respect to the Hybrid III dummy. This increasing tendency of the brain injury is also observed in the tests.

3. Head rotational velocity depends on the internal pressure of the airbag, the pressure stratage should be used for major component of BrIC. The strategy for achieving highest injury rating in NHTSA NCAP should be modified to meet the NHTSA Oblique RMDB BrIC requirements.

REFERENCES


