

A Comparison of the NHTSA Research Offset Oblique and Small Overlap Impact Tests and the IIHS Moderate and Small Overlap Tests

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ABSTRACT

The National Highway Traffic Safety Administration (NHTSA) and the Insurance Institute for Highway Safety (IIHS) have both developed crash test methodologies to address frontal collisions in which the vehicle's primary front structure is either partially engaged or not engaged at all. IIHS addresses Small Overlap crashes, cases in which the vehicle's primary front energy absorbing structure is not engaged, using a rigid static barrier with an overlap of 25% of the vehicle's width at an impact angle of 0°. The Institute's Moderate Overlap partially engages the vehicle's primary front energy absorbing structure using a deformable static barrier with 40% overlap at a 0° impact angle. The NHTSA has developed two research test methods which use a common moving deformable barrier impacting the vehicle with 20% overlap at a 7° impact angle and 35% overlap at a 15° impact angle respectively. In this paper, the authors present a case study in which an exemplar mid-size sedan was subjected to all four impact conditions. Following the NHTSA research procedures and IIHS protocols, the anthropomorphic test devices used in this study were THOR-NT (with LX instrumented lower legs) for the NHTSA research tests, and the Hybrid III AM50 for the IIHS tests. Differences with regards to resulting vehicle deformation, vehicle kinematics, and occupant kinematics were noted between the IIHS and NHTSA test methods and are discussed in this paper.

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INTRODUCTION

In a National Automotive Sampling System Crashworthiness Data System (NASS-CDS) study published in 2009 [1], the Insurance Institute for Highway Safety (IIHS) investigated 116 occupants of model year 2000 or later vehicles that were rated as "GOOD" in the Institute's moderate overlap crash test, who sustained AIS 3+ injuries in a frontal crash. The study revealed that approximately 24% of the vehicles in the dataset were involved in small overlap frontal impacts, defined as an impact outboard of the vehicle's main longitudinal energy-absorbing structures. As a result, the IIHS conducted additional research into small overlap frontal impact crashes [2], and eventually concluded that this crash mode is prevalent and should be added to its existing vehicle crash evaluation program, with the goal of more completely covering the spectrum of crashes which cause serious injuries in the real world. The IIHS studied various impact configurations and barrier types [3, 4], before finally settling on a collinear impact into a flat rigid barrier with an edge radius of 150 mm ("Flat 150") [5]. The IIHS

commenced small overlap vehicle evaluations in February of 2012, and published the first results and ratings in August of 2012 [6].

The small overlap crash mode has also been studied by the National Highway Traffic Safety Administration (NHTSA): in a 2009 study of 122 NASS-CDS fatal frontal crashes covering model year 2000 or newer vehicles [7], Bean et al. found that the main underlying cause of the fatalities was poor structural engagement between the vehicle and its collision partner. Subsequently, Rudd et al. highlighted the prevalence of AIS 3+ Knee-Thigh-Hip (KTH) injuries in this type of crash [8], pointing to the need for a test dummy with sufficient biofidelity of the KTH complex for laboratory evaluations. Using these findings as a foundation, the NHTSA began its own small overlap crash test research program, evaluating different impact configurations and both vehicle-to-vehicle and vehicle-to-Moving Deformable Barrier (MDB) tests. To date, the NHTSA has developed two research test procedures which use a common MDB impacting the vehicle with 20% overlap at a 7° impact angle (referred to as "Small Overlap Impact" or SOI).

and with 35% overlap at a 15° impact angle (referred to as “Offset Oblique”) respectively [9, 10, 11]. In order to obtain the best possible approximation of real-world occupant kinematics and observed injury patterns [8], the Agency decided to incorporate the THOR-NT test dummy in its test procedures. The NHTSA's research has not yet resulted in any regulatory (FMVSS) or consumer evaluation (NCAP) crash testing, due in part to the fact that the THOR dummy is still lacking well-defined injury criteria. The Agency has noted that they believe both the SOI and Offset Oblique impact configurations “demonstrate field injury risk,” but it has also highlighted a higher risk of head and chest injury in oblique impacts, and a higher KTH injury risk in the SOI configuration [9].

Prior to the publication of the initial IIHS ratings, Nissan Motor Company, Ltd. (NML) performed an independent study of 26 NASS-CDS small overlap frontal crashes involving AIS 3+ injured occupants of model year 2000-2008 vehicles [12, 13]. This dataset showed the following: (1) the IIHS test speed of 64 km/h (40 mph) probably covers 90% of real world cases, (2) approximately 70% of the NASS cases are oblique impacts with angles of 6°-14° to the left as opposed to collinear small overlap frontals, (3) approximately 40% of the NASS cases involve probable out-of position occupants, (4) intrusion in the IIHS test is smaller than in the NASS cases, (5) almost 70% of injuries in the NASS cases were not related to longitudinal intrusion, and (6) the head and chest predominantly sustain AIS 3+ injuries in the NASS cases, but intrusion measurement in the IIHS test only predicts lower extremity AIS 3+ injuries.

With the IIHS already conducting ongoing crash evaluations in the small overlap mode and the NHTSA continuing to further define their small overlap research test procedures, vehicle manufacturers are investigating the implications of the various impact configurations for vehicle design. This study compares four test configurations (the NHTSA's Offset Oblique and SOI tests and the IIHS moderate and small overlap tests). Crash tests were conducted according to the NHTSA research procedures, and the results were compared to those from IIHS small overlap and moderate overlap tests previously conducted on the same vehicle. Differences with regards to resulting vehicle deformation, vehicle kinematics, and occupant kinematics between the NHTSA RMDB and IIHS test methods are discussed.

METHODS/PROCEDURE

Four NHTSA tests using the Research Movable Deformable Barrier (RMDB) (as described in [9]) were conducted with a mid-size sedan as a surrogate. A limitation to this study is these results represent only a single vehicle model, and similar results and conclusions may not apply to different vehicles.

Two tests were conducted in the Small Overlap impact configuration and two tests were conducted in the Offset Oblique configuration. Results from these tests were compared with results from the IIHS Small Overlap and Moderate Overlap tests of the same vehicle.

Vehicle Preparation for the NHTSA RMDB Tests

Four vehicles with identical chassis and powertrain configurations were prepared for testing according to the NHTSA's research test procedure. The mass of the tested vehicles (as well as basic overall dimensions) were as listed in Table 1; masses of the vehicles tested in the IIHS modes are also listed.

Table 1. Mass and overall dimensions of the vehicles tested in the NHTSA RMDB and IIHS modes.

Test Mode	Test Mass [kg]	Overall Width [mm]	Overall Length [mm]	Wheelbase [mm]
NHTSA RMDB Offset Oblique 1	1867	1859	4841	2776
NHTSA RMDB Offset Oblique 2	1866			
NHTSA RMDB Small Overlap 1	1868			
NHTSA RMDB Small Overlap 2	1870			
IIHS Moderate Overlap	1785			
IIHS Small Overlap	1741			

Post-test vehicle structure assessment was conducted according to the NHTSA's current research procedure as of July 2013, which incorporates the main structural assessment of the occupant compartment used by the IIHS. Accelerometers were installed on the vehicle tunnel per IIHS protocol and the data from these channels were integrated to determine vehicle velocity and displacement discussed later in subsequent sections. Interior and exterior surfaces of the vehicle were painted for improved video views, as well as individual components of the suspension, vehicle underbody, and engine compartment. Several non-structural components were removed for the observation of load-bearing members of the front end. Fifteen on-board and off-board cameras were used to record the tests.

Anthropomorphic Test Devices (ATD)

In this study, a Test Device for Human Occupant Restraint (THOR) representing 50th percentile male was positioned in the driver's seat. This was an NT-level THOR without Mod Kit and was equipped with LX instrumented lower legs. An instrumented Hybrid III (50th percentile male (AM50)) was positioned in the front passenger's seat. The ATDs were seated according to the NHTSA frontal seating procedure for AM50. The ATDs were painted to allow for observation of any contact with interior surfaces of the occupant compartment.

Test Configurations

NHTSA RMDB Small Overlap and Offset Oblique Tests

The NHTSA RMDB testing was conducted in accordance to the NHTSA RMDB test procedure. As shown in Figure 1(a), the vehicle is impacted by a moving deformable barrier travelling at 90.1 km/h (56 mph) at an impact angle of 15° and an overlap of 35% of the vehicle's width in the Offset Oblique test. In the Small Overlap test, the vehicle is impacted at an angle of 7° and 20% overlap, also at a speed of 90.1 km/h (Figure 1(b)).

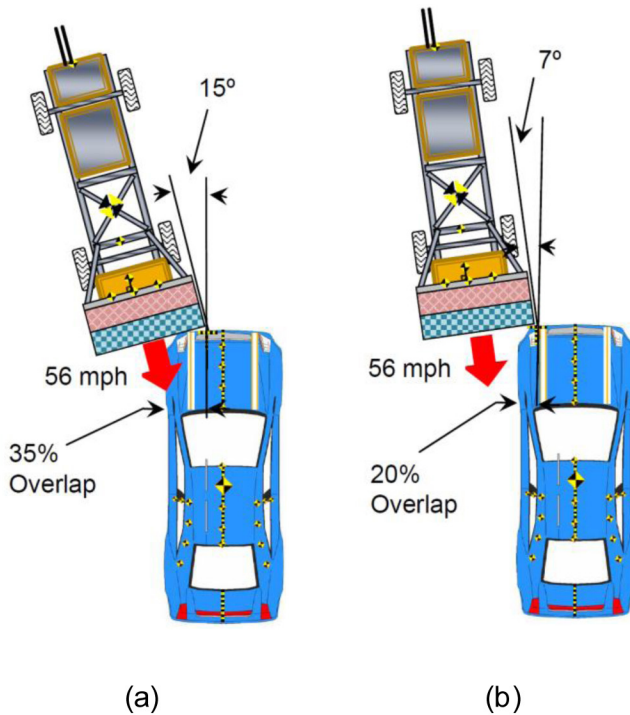


Figure 1. Test configurations of the NHTSA RMDB Offset Oblique (a) and NHTSA RMDB Small Overlap (b) tests [14].

Comparison with IIHS Moderate Overlap and Small Overlap Tests

The data from the NHTSA RMDB Offset Oblique impact tests was compared with that from the IIHS Moderate Overlap test (tested in accordance with "Moderate Overlap Frontal Crashworthiness Evaluation Crash Test Protocol (Version XII) August 2007" [15]). In the Moderate Overlap test, the vehicle, travelling at 64.4 km/h (40 mph) impacts a fixed deformable barrier at 0° impact angle and 40% overlap (Figure 2(a)). Results from the NHTSA RMDB Small Overlap impact tests were compared with those from the IIHS Small Overlap test (tested in accordance with "Small Overlap Frontal Crashworthiness Evaluation Crash Test Protocol (Version I) October 2012 [16]). In the IIHS Small Overlap test, the vehicle, travelling at 64.4 km/h, impacts a fixed rigid barrier at 0° impact angle and 25% overlap (Figure 2(b)). In both of the IIHS tests, a Hybrid III with instrumented lower legs (50th percentile male) is seated in the driver position.

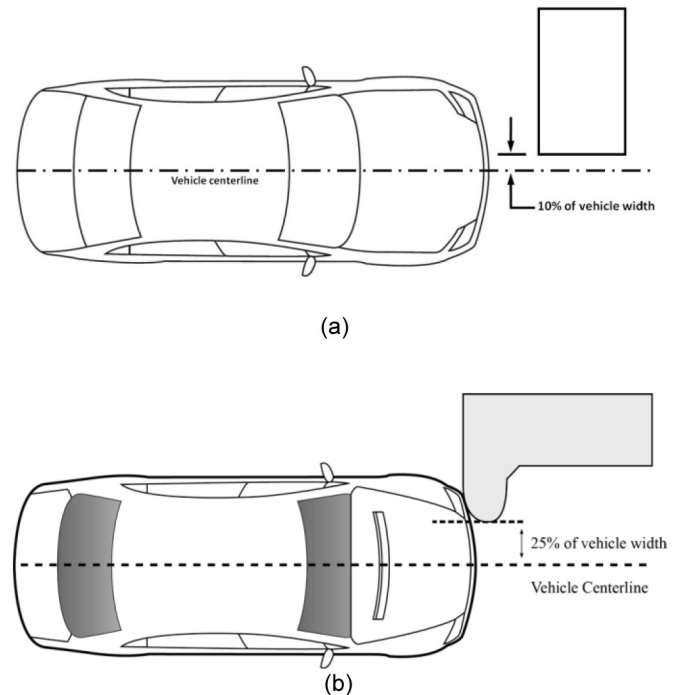


Figure 2. Test configurations of the IIHS Moderate Overlap (a) and Small Overlap (b) tests [15,16].

RESULTS & DISCUSSION

Comparisons were made with regard to the following to understand what differences exist between the NHTSA RMDB and IIHS test modes:

1. vehicle deformation
2. vehicle kinematics
3. occupant kinematics

Vehicle Deformation

Vehicle deformation was assessed by measuring intrusion at pre-defined locations around the occupant compartment. Figure 3 shows the percentage difference in intrusion of the NHTSA RMDB test modes versus the corresponding IIHS test modes (i.e., 0% in this figure represents the same measured intrusions between the two test types).

In the NHTSA RMDB Small Overlap tests, the intrusion at most of the measured locations was higher than was observed in the IIHS Small Overlap test, ranging from 0 to 282%. The intrusion was also greater in the NHTSA RMDB Offset Oblique tests than in the IIHS Moderate Overlap test in all locations, ranging from 36% to 4191% great

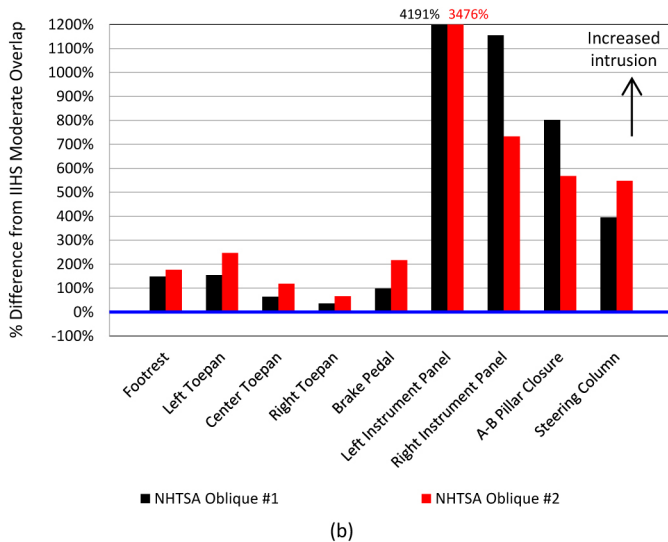
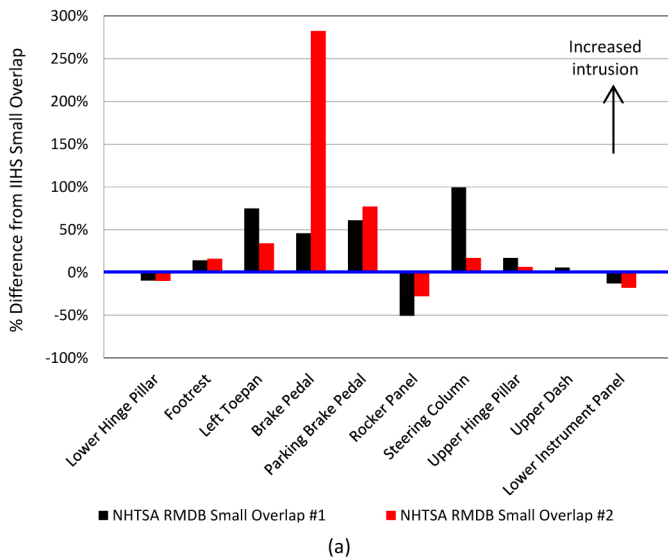


Figure 3. Vehicle deformation of vehicles tested in the NHTSA RMDB Small Overlap and IIHS Small Overlap modes (a), and the NHTSA RMDB Offset Oblique and IIHS Moderate Overlap modes (b).

Differences in intrusion results between the IIHS and NHTSA RMDB test modes may be attributed to two factors:

- total change in velocity (delta-V) characteristics in the IIHS vs. NHTSA RMDB test modes
- the vehicle's interaction with the barrier due to the different test configurations between the IIHS and NHTSA RMDB modes

The increased deformation observed in the NHTSA RMDB test modes is partly attributed to the difference in the total change in velocity (delta-V) between the NHTSA and IIHS test modes. It should be noted the subsequent delta-V characteristics of the NHTSA RMDB tests apply only to vehicles of this mass range due to the fixed mass (and thus, fixed kinetic energy) of the cart. This is a departure from existing IIHS and NHTSA frontal impact test modes which have a fixed barrier, and the kinetic energy of the crash event is directly proportional to the vehicle

mass and impact velocity. In addition to the longitudinal kinetic energy differences, this mode also inputs a fixed amount of lateral kinetic energy. This lateral kinetic energy input in an injury test is not currently present in any existing frontal crash mode.

Figure 4 shows the delta-V comparison for the NHTSA RMDB Offset Oblique and IIHS Moderate Overlap, with the IIHS velocity data offset (to begin at zero) for comparison purposes. This data was trimmed to show only the data up to approximately 100 ms. At this time, the vehicles in the NHTSA RMDB tests have been accelerated rearward to a point where the vehicle rearward velocity matches the reduced forward velocity of the RMDB. In the IIHS test, the vehicle has bottomed-out on the IIHS barrier around this time, and moves in a rearward direction (i.e., negative velocity). It is seen that the delta-V in the NHTSA RMDB Offset Oblique tests have an earlier onset as well as a steeper slope than that of the IIHS Moderate Overlap test.

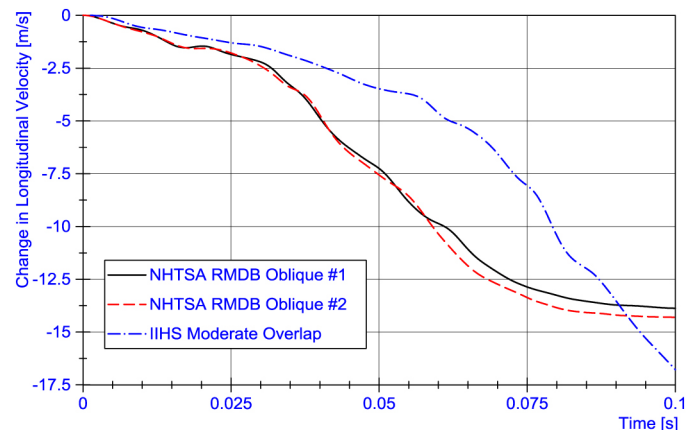


Figure 4. Delta-V for the NHTSA RMDB Offset Oblique and IIHS Moderate Overlap tests.

The more severe crash pulse of the NHTSA RMDB Offset Oblique tests compared to the IIHS Moderate Overlap can be partially attributed to differences in the barrier between these test types. Figure 5 shows the structure of the two barrier types. The NHTSA RMDB is both thicker in depth and has higher stiffness than the IIHS barrier. The effect of this barrier difference is evident in the longitudinal acceleration of the vehicle (Figure 6(a)), which shows larger spikes in acceleration earlier in the NHTSA RMDB Offset Oblique tests. The longitudinal acceleration is also plotted against vehicle displacement and is shown in Figure 6(b). Because the vehicle in the IIHS test mode travels in a different direction compared to the NHTSA RMDB tests from the beginning of the crash event, the displacement data from the IIHS test was inverted to allow for a more meaningful comparison with the NHTSA RMDB tests. In the NHTSA RMDB tests, the peak acceleration occurs soon after the vehicle begins travelling rearward, since the vehicle does not travel rearward significantly until the RMDB deforms the vehicle's front end structures and nears the occupant compartment. In the IIHS test, the vehicle continues