

NHTSA's Proposed Frontal Oblique Impact Test Protocol: Analyses and Evaluation

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ABSTRACT

On December 2015, The National Highway Traffic Safety Administration (NHTSA) published its proposal to implement U.S New Car Assessment Program (NCAP) changes covering three categories of crashworthiness, crash avoidance and pedestrian protection, beginning with the 2019 model year. The crashworthiness category included a new frontal oblique impact (OI) test protocol. The test comprises of a new Oblique Moving Deformable Barrier (OMDB), new THOR 50th percentile male (THOR-50M) anthropomorphic test device (ATD), and a new test configuration. An OMDB of 2,486 kg (5,480 lb) impacts a stationary target vehicle at a speed of 90 kph (56 mph) at an angle of 15 degrees with a 35% barrier overlap with the front end of the target vehicle. In vehicle-to-vehicle collisions, the lighter weight vehicle experience higher velocity change and higher acceleration levels, thereby, occupants in the lighter vehicle experience higher injury risk. This paper describes the analyses of a series of 31 OI tests conducted by NHTSA, in which the target vehicles used were of different sizes and weight distribution ranging between 1034 Kg (SMART)-2624 Kg (Silverado).

Deformation Energy in the OMDB was calculated from the honeycomb deformation and its associated stiffness. Target vehicle Deformation Energy (DE) in each of the 31 OI tests was determined and compared to its 56 kph (35 mph) NCAP DE. This was shown in a diagram of DE versus mass ratio of the target vehicle to the OMDB. THOR M50 dummy responses for each test were plotted against target vehicle Velocity Change (Δv_2), calculated from momentum equation and from test's velocity time histories. Results indicated that target vehicles absorb more DE in the proposed OI compared to a 56 kph (35 mph) full frontal barrier impact. Lighter weight vehicles, in particular, have to manage approximately 50-60% more DE in the proposed OI. Larger vehicles that have similar weight to that of the OMDB manage approximately same DE as in the NCAP full frontal barrier impact. Therefore lighter vehicles will require significant structural reinforcing and stiffening to manage the crash energy in the OI. This may have a negative impact on attributes such as occupant safety, vehicle compatibility, and fuel economy. For example, it could result in a stiffer crash pulse in light vehicles which may lead to issues associated with occupant safety in all seating position, elderly occupants in particular. Injury risk associated with THOR-M50 dummy responses in NHTSA's OI tests showed weak or no correlations with (Δv_2). The proposed OI mode did not demonstrate the expected injury trend with velocity change which may be attributed to potential issues with the barrier mass, barrier stiffness, THOR dummy, and the test configuration. It is concluded that further research is needed to develop appropriate OI test parameters, OMDB, and dummy type and / or injury criteria.

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INTRODUCTION

Regulatory and Public Domain (PD) frontal impact test protocols continue to evolve globally in order to address injuries and fatalities associated with various real world crash modes. Among the existing test protocols issued by The National Highway Traffic Safety Administration (NHTSA), The Insurance Institute of Highway Safety (IIHS) and the European New Car Assessment Program (Euro-NCAP) are: Fixed Full Rigid Barrier (FRB) impact, fixed Offset Deformable Barrier (ODB) impact with moderate overlap, and fixed Small Overlap Rigid Barrier (SORB) impact. The crash barriers are fixed and the vehicle, which carries initial kinetic energy, runs into the barriers in a collinear fashion of impact with either full, moderate, or small overlaps

[1, 2, and 3]. These test protocols are designed to assess self-protection in terms of structural intrusions and Hybrid-III 50th% male and 5th% female Anthropomorphic Test Device (ATD) responses.

In June 2015 Euro-NCAP introduced a new frontal impact protocol as part of the 2020 Euro-NCAP roadmap to be implemented in 2020 [4, 5]. This test protocol is using new Moving Progressive Deformable Barrier (MPDB) and new THOR-M50 ATD and is designed to assess self and partner protection. It is a 50% overlap colinear frontal impact in which both the MPDB and the vehicle are moving against each other with a fixed initial speed of 50 kph (31 mph). Self-protection is assessed through structural deformation and THOR dummy responses and the partner protection is assessed through the aggressivity metric, calculated from the MPDB

deformation map. On December 2015, NHTSA published its proposal to implement U.S new NCAP changes beginning with the 2019 model year [1]. The crashworthiness category included a new frontal Oblique Impact (OI) test protocol. The test comprises of a new Oblique Moving Deformable Barrier (OMDB), new THOR-M50 ATD, and a new test configuration. An OMDB of 2,486 kg (5,480 lb) impacts a stationary target vehicle at a speed of 90 kph (56 mph) at an angle of 15 degrees with a 35% barrier overlap with the front end of the vehicle. Table 1 shows a brief description of the current and newly proposed frontal impact test protocols. It summarizes various existing and proposed frontal impact test configurations issued by regulatory and public domain agencies.

Table 1. Frontal Impact Crash Modes and Test Characteristics

	Unit	NCAP	IIHS ODB	IIHS SORB	NHTSA OI 2019	New Euro NCAP 2020
						
Barrier Type		Fixed Rigid Wall	Deformable Barrier	Rigid Wall with R 6" Edge	Moving Deformable Barrier	Moving Deformable Barrier
Barrier Stiffness	Psi	Rigid	100 psi	Rigid	0-300 mm, 100 psi 300-600mm, 245 psi	0-100mm, 50 psi 100-400 mm, 50-100psi 400-700 mm, 100-245psi
Overlap		100%	40%	25%	35%	50%
Oblique	Degr	0	0	0	15	0
Initial Speed	Kph	56 / 35	64 / 40	64 / 40	90 / 56	50 / 31 to -50 / -31
Bullet mass	Kg	Infinite	Infinite	Infinite	2486	1450
Protection		Self Protection	Self Protection	Self Protection	Partner Protection	Partner Protection Compatibility

As a result of the NHTSA study published by Bean *et al.* [5], NHTSA initiated a vehicle crash research program with the intent to develop a test protocol that replicates real-world vehicle kinematics and injury potential in a small overlap impacts and oblique offset impacts [6]. This research led to the development of a Research Moving Deformable Barrier (RMDB) and an opportunity for improved ATD to be used in a RMDB-to-Vehicle impact test protocol. The RMDB was a modified FMVSS 214 barrier with a test weight of approximately 2500 kg [7]. Since then NHTSA has been investigating a new frontal OI test mode in which a RMDB impacts a stationary vehicle at 90 kph, a 15 degree angle, and a 35% vehicle overlap. The test utilizes The Test Device for Human Occupant Restraint (THOR) dummy positioned in both the driver and passenger seat. The dummy has been developed to enhance the bio-fidelity of Hybrid III which is currently used in frontal crash tests.

In this paper a series of 31 OI tests conducted by NHTSA was selected and analyzed to better understand the feasibility and validity of the proposed OI test protocol. The DE for both the impacted vehicle and the OMDB were calculated and compared to their respective DE in the 56 kph (35 mph) NCAP test. Injury indices measured by the THOR dummy in the test series were plotted against (Δv) to better understand the THOR dummy suitability in injury assessment to replicate the injury outcome and injury trends observed in real-world crashes [8, 10, 11]. The following sections provide the description and the analyses for the selected NHTSA's OI, in which the target vehicles used were of different sizes and weight distribution ranging between 1034 Kg (SMART) to 2624 Kg (Silverado).

OBLIQUE IMPACT TEST DESCRIPTION AND ANALYSIS

Oblique Impact Test

The selected OI test series conducted by NHTSA included different classes of vehicles consisting of a sub-compact car on the light end and full-size truck on the heavy end as shown in Figure 1. All tests were performed according to the OI test protocol shown in Figure 2.

The THOR M50 dummy was positioned at the driver's seat according to the Federal Motor Safety Standard FMVSS 208 seating procedure. The OMDB impacted a stationary vehicle at a speed of 90 kph (56 mph) while the target vehicle was placed at a 15-degree angle and a 35 percent initial overlap of the struck vehicle front-end width with the OMDB (see Figure 2). The total weight of the OMDB was 2,486 kg (5,480 lb) in which the barrier honeycomb consisted of two layers with different stiffness [7]. The stiffness of the first 300 mm thick honeycomb layer was 0.724 Mpa (100 psi) and that of the second 300 mm thick honeycomb layer was 1.71 Mpa (245 psi).

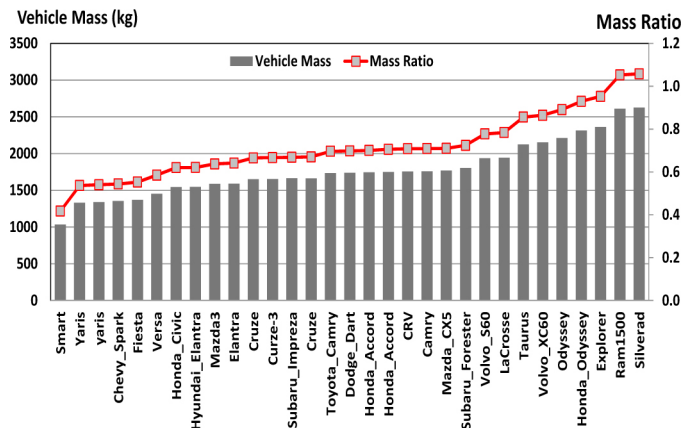


Figure 1. Vehicle mass and mass ratio in the NHTSA's OI tests

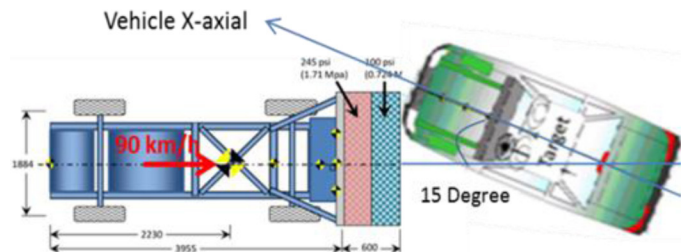


Figure 2. NHTSA Oblique Impact test-setup, top view

Vehicle Kinematic

The OMDB centerline makes an angle of 15 degrees with the vehicle longitude center line, according to the initial test configuration. At time zero, at the first point of the contact of the barrier with the vehicle, the OMDB imposes both longitudinal and lateral components of impact velocities of 87 kph (54.1 mph) and 23.3 kph (14.5 mph), respectively and a 35% initial overlap with the vehicle. The initial percentage of overlap generates an initial contact zone between the barrier and the impacted front end of the vehicle. During the crash, both of the barrier and vehicle continue to rotate causing the contact zone and the impact force acting on it to change. Example of this behavior

is shown in Figure 3, in which between time zero and 80 ms of the crash the angle between the barrier and the target vehicle centerlines changed from 15 degrees to 30 degrees and impact contact zone between the barrier and the vehicle increased from 35 % to 50 % overlap. The progressive change in the Principle Direction of Impact Force (PDIF) and the progressive increase in the contact area during the crash cause different kinematics of the occupants compared to co-linear impacts (Figure 4). The changes in the PDIF and contact area necessitate the need of struck target vehicles to manage increased DE than what is designed for in their 56 kph (35 mph) NCAP test.

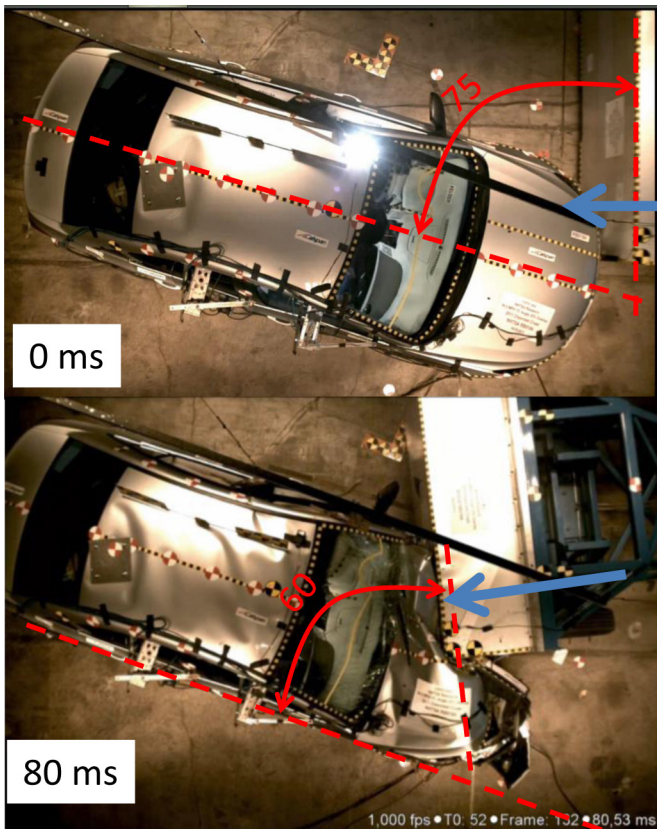


Figure 3. Changes in initial impact angle, direction of the impact force, and contact area between the OMBD and target vehicle at 80 ms



Figure 4. Examples of OI dummy kinematics shown at rebound time 116 ms

The Target Vehicle Crash Pulse in OI

Resulted crash pulse signatures in target vehicles in frontal OI are distinguishably different than those obtained in any other existing frontal impact collinear modes, for the same vehicles. Investigating the difference may help with the understanding of the unique

occupant kinematics and the excessive DE needs in OI. Two in-house OI tests for an SUV and a sedan (SED) were conducted in which their acceleration time-histories in the longitudinal X, and lateral Y, directions are shown in Figure 5. Shapes of the accelerations time-histories of the SUV and SED in the OI tests are similar. The longitudinal X-acceleration in the SUV is slightly higher than that of the SED. However, around 40 ms the lateral Y-acceleration component in the SED is slightly higher than the longitudinal X-acceleration component of the SUV. This is a unique behavior observed in the frontal OI in which the lateral component has a significant contribution to the deformation energy absorbed by the target vehicle. This also confirms the fact that although the OI is a frontal impact at time zero, but the PDIF continues to change towards the lateral direction during the crash. Figure 5 shows approximately that up to 20ms of the crash only deformation of the front layer of the barrier and the vehicle's bumper occurred. Therefore both the SUV and SED have similar deceleration time histories. When the deformation progresses to the second layer only the target vehicle continues to crush until energy balance is reached, due to the high stiffness of the barrier second honeycomb layer.

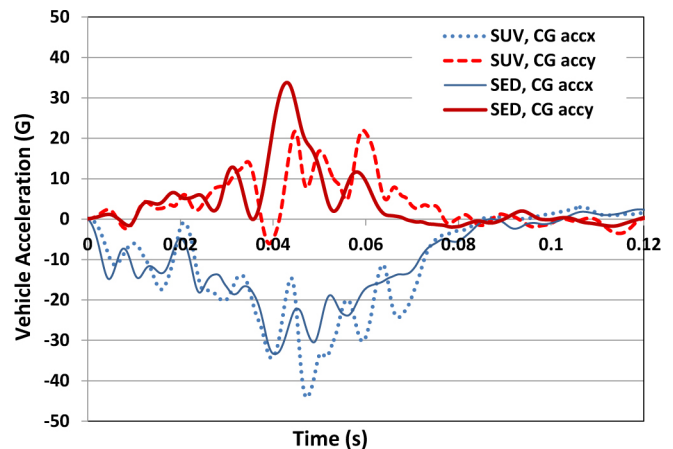


Figure 5. The longitudinal X-acceleration and lateral Y-acceleration for an SUV and Sedan in OI test

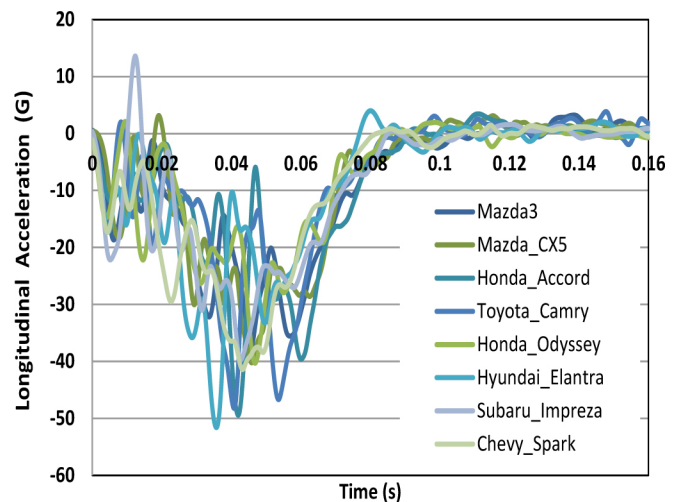


Figure 6. Longitudinal X-accelerations in target vehicles