

An Examination of Crash and NASS Data to Evaluate the Field Relevance of IIHS Small Offset Tests

P. Prasad
Prasad Engineering, LLC

D. Dalmotas and A. German
D. J. Dalmotas Consulting Inc.

ABSTRACT

This paper presents the analysis of a series of frontal crash tests conducted by the Insurance Institute of Highway Safety that are commonly referred to as Small Overlap Impacts (SOI). The occurrence and severity of such frontal impacts in the real world were estimated using two different methods. Both methods used the National Automotive Sampling Scheme (NASS), which is a stratified sample of crashes in the US. The first method utilized an algorithm commonly known as Frontal Impact Taxonomy (FIT). The second method was based on comparison of deformation patterns of vehicles involved in frontal crashes in the NASS data files with those produced in tests conducted by the IIHS. FIT analysis of the data indicate that approximately 7.5% of all 11-1 o'clock frontal crashes in NASS are represented by the IIHS SOI test condition and they account for 6.1% of all serious-to-fatal injuries to front seat occupants restrained by seat belts and airbags. Based on the analysis of test and crash front end damage data, it is estimated that the IIHS SOI test mode represents 3% to 8% of all fatal crashes and 4.6 to 9% of all MAIS3+F injury producing frontal crashes.

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INTRODUCTION

Light vehicles are currently designed to meet or exceed the requirements of the FMVSS 208 in frontal impacts. This regulation includes perpendicular and angular tests against a rigid barrier and a 40% offset test against a deformable barrier. The rigid barrier tests are conducted at 25 mph with unbelted dummies, and at 35 mph with belted dummies. Whereas the offset, deformable barrier test is conducted at 25 mph for the FMVSS 208, vehicles are also designed to perform well in the IIHS 40% offset, deformable barrier tests. Over the years, most vehicles have achieved the highest ratings in the IIHS frontal tests, and also good ratings in NHTSA's frontal NCAP. This has prompted the IIHS and NHTSA to investigate additional test configurations for frontal impacts.

The IIHS has started conducting a 25% offset test, also referred to as SOI or Small Overlap Impact. In this test the front rail of the vehicle is not engaged. Brumbelow and Zubry have presented their rationale for such a test in a 2009 ESV paper. [1] Meanwhile, NHTSA has embarked on a research project that would lead them to adopt a somewhat different small overlap test configuration. NHTSA's rationale for embarking on the research is based on a study that investigated fatal frontal crashes in the NASS database in which the occupants were belted and the vehicles were equipped with frontal airbags. In

the report, a little over 100 such fatalities were identified in the NASS files for detailed study by a group of NHTSA experts. [2] A large number of these fatalities were in high velocity impacts, but a substantial number were in crashes where structural interaction between the striking and the struck structures were judged to be inadequate. NHTSA's research is aimed at developing a test procedure in which some of the vehicle deformations seen in the NASS cases could be duplicated. Their test procedure is nearly finalized and is most likely to be a test involving a small overlap of the front-end of a vehicle against a movable deformable barrier.

A study sponsored by the Alliance has been conducted, the main aim of which was to review the IIHS test results and evaluate the field relevance of such tests. To establish the field relevance, the frequency of occurrence of the crash types, and the resulting rates of serious and fatal injuries, in real world frontal crashes had to be estimated from publicly available databases. For this study, both NASS and the CIREN databases were utilized. The results of the CIREN study will not be reported in this paper, although the results were complimentary to the results of the NASS data analysis. Note that the IIHS tests produce deformation patterns that can be considered to be a subset of those produced in real world crashes. This is a matter of active research being pursued by the NHTSA.

universities such as the Medical College of Wisconsin and George Washington University (GWU), and vehicle manufacturers. [3, 4, 5, 6, 7, 8, 9]

In the IIHS tests the overlap is 25% against a rigid, fixed barrier. The crash geometry is collinear. NHTSA has conducted testing in two configurations- 20% and 35% overlap of vehicle front-ends with a Movable Deformable Barrier at 7 degrees and 15 degrees to the longitudinal axis of the vehicle. NHTSA appears to have settled down to a test with a Research Movable Deformable Barrier (RMDDB) whose longitudinal axis is 15 degrees to that of the struck vehicle with a 35% overlap of the vehicle being tested. We will refer to the IIHS tests as Small Overlap Impacts (SOI) and the NHTSA tests as Oblique RMDDB tests.

The major findings relative to Small Overlap Impacts (SOI) of the current study are discussed next in this paper. Detailed study of crash tests conducted by the IIHS and on its website were conducted and guided the NASS queries. The literature study and crash data analysis cover pertinent literature available as of writing of this paper, and the currently available NASS data were studied.

LITERATURE SURVEY

In 1993, Planath et al. reported the results of a study of frontal crashes in Sweden. [10] A class of frontal crashes labeled as Severe Partial Overlap Crash (SPOC) occurred 3% of the time, but accounted for 14% of AIS2+ injuries to occupants of vehicles involved in such crashes. In a subsequent paper, Planath and Nilsson compared several frontal crash tests in regulations and mentioned that Volvo had developed an additional test procedure for SPOC that consisted of a 35% overlap, frontal test against a rigid barrier at 64 km/h. [11] It was also stated that "Exclusive use of SPOC in the development process would however be detrimental." This test did not gain too much attention, perhaps due to the introduction of the European 40% overlap test against a fixed deformable barrier in the European regulation and by the IIHS in the USA and by NCAPs around the world. The results of further crash studies in Sweden performed by Lindquist et al. in 2003 and 2004 focused the attention of researchers to a class of frontal crashes that are now commonly referred to as Small Overlap Impacts (SOI). [12-13] Lindquist claimed that nearly half of all frontal crash fatalities in Sweden were in these SOI's. In these crashes the front longitudinal members were not engaged resulting in substantially greater passenger compartment intrusions than in frontal crashes in which they were. The 2003 and 2004 studies kicked off similar studies in US, Europe and Australia. The IIHS conducted a study of frontal crashes of vehicles that were rated "Good" in their frontal crash program and reported their findings in 2009. [1] The IIHS followed up by conducting several frontal crash tests to help them develop an addition to their frontal crash test program for safety rating of new vehicles. This test is conducted at 64 km/h against a rigid

barrier that overlaps 25% of the front-end of the vehicle. Our own examination of post-test photographs of tested vehicles show that the frontal rails are not engaged in these tests.

Simultaneously, NHTSA conducted a meeting of NHTSA experts to examine the reasons why vehicle occupants are killed despite being belted and protected by airbags in frontal impacts. [2] A detailed study of 122 fatal frontal crashes in NASS was performed in which primary and secondary causes were subject to group consensus. 49 of the 122 crashes (40%) were considered to be exceedingly severe or had anomalies. 29 of the 122 (24%) were corner and/or oblique impacts in which it was judged that the primary factor affecting fatalities was limited structural engagement of the front longitudinal rails of vehicles that are designed for energy absorption. Of the 122 fatalities 17 (14%) were due to underride, 15 (12%) were because the occupant was vulnerable, and 8 (7%) were in the "other" category. This paper led to a research program of crash testing by NHTSA and some of the test results have been reported by Saunders et al. [14]

Further studies aimed at identifying the real world distribution of frontal crashes, in terms of overlap, in the NASS database have been published. The first study was conducted by Sullivan et al., in which all NASS frontal crashes were distributed in eight different bins. [15] The proportional contribution of each bin was determined in terms of frequency of occurrence and injury severity. Scullion et al., 2010, modified the Frontal Impact Taxonomy study of Sullivan et al. into seven bins and concentrated on identifying the frequency of occurrence of and injury risk in small overlap frontal crashes in NASS. [16] The results of this study did not agree with previous findings of Lindquist and the MCW studies. Scullion's data indicated that the risk of AIS3+ injuries in small overlap frontal crashes was not significantly different than that in moderate offset and offset crashes. The NCAC (GWU National Crash Analysis Center) group has continued to study the Frontal Impact Taxonomy and published several papers in the last two years. [17, 18, 19, 20] In their subsequent studies the relative importance of narrow offset/overlap crashes has not changed.

CRASH DATABASE RESEARCH

NASS is a large nationally representative database in which it is relatively easier to filter down to the type of crashes addressed by the small overlap/narrow offset research crashes and those conducted by the IIHS. NASS has stratified sampling and in some cases overly influential weighting factors have been identified. Given some of the issues associated with overly influential weighting factors and sparseness of data as subsets are created, a vast majority of the current analysis is based on available raw data, i.e. un-weighted data.

Crash Test Database

Detailed study of occupant responses and general vehicle kinematics in tests conducted by the IIHS and on its website have been included in this study.

Each test vehicle was assigned a CDC (Collision Deformation Classification) by an experienced crash investigator. The NASS database was searched for the CDC's observed in the crash tests. The cases identified from the NASS files were then checked manually to identify the cases that came close to those seen in the crash tests.

This paper covers the results of the study. The IIHS Crash test results are discussed first as they helped to focus the queries of the NASS.

IIHS Crash Tests

Small-Overlap Offset Crashes are being conducted by IIHS and have become part of the IIHS safety rating system. To date, 65 new vehicles have been crashed and their engineering data and ratings are publicly available. The specific test procedure and rating protocol are available at the IIHS website. Briefly, the test is conducted against a narrow fixed barrier, engaging approximately 25% of the front-end of the vehicle. The crash velocity against the barrier is 40 mph (64 km/h). In general, the front-rail is not engaged during the crash. Generally, there is substantial impact to the front wheel by the barrier. In some cases, the vehicle is deflected by the barrier, but in other cases, the engagement with the barrier is prolonged. In all cases, substantial rotation of the vehicle occurs. The rating protocol includes the responses of a 50th percentile male Hybrid III dummy, intrusion of the dash, steering column floor-pan, etc. into the passenger compartment, and occupant interaction with the airbag (e.g. stable or unstable interaction).

Out of the sixty five vehicles that have been rated by IIHS to date, 13 have been rated "Good", 17 "Acceptable", 19 "Marginal" and 16 "Poor". An analysis of the occupant responses considered for the safety evaluation of the tested vehicle has been conducted for the 65 crash tests. The average and standard deviations of HIC, chest deflections, peak femur loads, probability of Knee-Thigh-Hip injury (KTH PI) and the Tibia Index (TI) were calculated for the four rating categories, and are shown in [Table 1](#). The standard deviation for each response is shown within brackets. Although neck load data are available, they are not shown in the table due to being fairly low in all categories.

Table 1. Average Occupant Responses in the IIHS Small Offset Tests

Rating	HIC	HIC15	Chest Defln.(m m)	Femur Load (kN)	KTH PI(%)	Max. TI
Good	232 (115)	137 (89)	25.15 (1.56)	2.18 (1.59)	0.62 (1.02)	0.63 (0.22)
Acceptable	233 (97)	140 (78)	22.82 (3.05)	2.31 (0.95)	0.31 (0.40)	0.73 (0.19)
Marginal	244 (119)	139 (70)	22.84 (4.32)	4.69 (3.31)	10.56 (26.16)	1.19 (0.62)
Poor	258 (142)	150 (92)	21.81 (3.59)	6.05 (2.79)	18.69 (26.69)	1.21 (0.39)

From the above table, it can be seen that the head and chest injury risks are nearly the same in all categories. There is a trend of increasing femur loads which translates into greater probability of Knee-Thigh-Hip complex injuries, e.g. the probability of KTH injury is negligible in the "Good" and "Acceptable" vehicles, but nearly 19% in the "Poor" vehicles. There is a similar trend of increasing Tibia Index as the ratings get lower.

Table 2. Average Occupant Responses in the IIHS Moderate Offset Tests

Rating	HIC	Chest Deflection(mm)	Femur load (kN)	KTH PI (%)	Max. TI
Good	218 (96)	27.33 (4.1)	1.11 (1.18)	0.17 (0.4)	0.51 (0.08)
Acceptable	180 (115)	29.44 (4.6)	1.74 (1.31)	0.22 (0.67)	0.56 (0.23)
Marginal	179 (68)	26.4 (3.95)	1.61 (1.1)	0.14 (0.38)	0.41 (0.08)
Poor	175 (40)	27.8 (7.63)	2.06 (0.98)	0 (0)	0.46 (0.07)

The above results were compared with those of a subset of 28 in the IIHS moderate offset crashes. In general the HIC's were generally equally low and the chest deflections were somewhat higher than those in the small-offset tests. As expected, the lower extremity responses were substantially lower in the moderate offset tests. Comparing the dummy occupant responses between the low offset and the moderate offset tests, one would conclude that the crash environment in the low offset test is more conducive to lower extremity injuries as opposed to that in the moderate offset test. It is also obvious that the rating is not affected much by the occupant responses, but rather by other criteria like intrusion. Intrusion of the dash, instrument panel, steering wheel and base of A-pillar, etc. are certainly higher in the small overlap tests. However, these intrusions did not greatly affect head and chest injury risks. The effect of intrusion is essentially to increase the potential of lower extremity injuries.

The velocity-time histories of all 65 tests were divided up in two sets- top ten highest residual velocities and top ten lowest residual velocities- and are shown in [figures 1](#) and [2](#).

The longitudinal velocity-time histories for the top ten in residual velocities are shown in [Figure 1](#). It can be seen that the maximum change in velocity is in the 100 to 150 ms time frame after the initiation of impact. These vehicles had residual velocities ranging from 21 km/h to 30 km/h reflecting deflection from the barrier. It can be seen in [Figure 2](#) that the residual velocities of ten vehicles ranged between 2km/h to 10 km/h