# The Accuracy of Velocity Change Estimates in Small Overlap Frontal Crashes

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**Abstract –** Small overlap frontal crashes are defined by a damage pattern with most of the vehicle deformation concentrated outboard of the main longitudinal structures. These crashes are prominent among frontal crashes resulting in serious and fatal injuries, even among vehicles that perform well in regulatory and consumer information crash tests. One of the critical aspects of understanding these crashes is knowing the crash speeds that cause the types of damage associated with serious injuries. Laboratory crash tests were conducted using 12 vehicles in three small overlap test conditions: pole, vehicle-to-vehicle collinear, and vehicle-to-vehicle oblique (15-degree striking angle). Field reconstruction techniques were used to estimate the delta V for each vehicle, and these results were compared with actual delta V values based on vehicle accelerometer data. Estimated delta Vs were 50% lower than actual values. Velocity change estimates for small overlap frontal crashes in databases such as NASS-CDS significantly underestimate actual values.

## INTRODUCTION

Small overlap frontal crashes are defined as those in which the majority of vehicle deformation to the front plane is located outboard of the main longitudinal frame rails. Recent studies have found that these crashes constitute a substantial proportion of frontal crashes responsible for serious injuries and fatalities. A study of National Automotive Sampling System (NASS) Crashworthiness Data System (CDS) cases of vehicles with good ratings in the Insurance Institute for Highway Safety (IIHS) frontal offset test and involved in crashes where an occupant was seriously injured or killed found that 24% of the vehicles were involved in small overlap crashes [1]. More than a third (34%) of fatal frontal crashes in Sweden occurred in crashes that caused no deformation of the longitudinal members [2]. Because the primary structural components are not loaded, these crashes can result in significant occupant compartment intrusion. In another NASS study of small overlap crashes, occupant compartment intrusion was the primary injury mechanism and was found to have a strong correlation with overall injury severity [3].

As a result of these findings, IIHS is studying small overlap frontal crashes as a possible means to further improve frontal crashworthiness designs through regulatory or consumer information testing. A series of crash tests have been conducted at various speeds and crash configurations, including the three crash modes identified in the NASS analysis of small overlap crashes [3]: pole, vehicle-to-vehicle collinear, and vehicle-to-vehicle oblique. These research tests are necessary to determine appropriate test parameters representing real-world crashes and to accurately correlate crash test results with NASS data.

NASS estimates of velocity change (delta V) have been shown to have increased error as the percentage of vehicle overlap decreases. In the most recent update of IIHS data, reconstructed estimates in 40% offset tests were 28% lower than actual delta V values [4]. Stucki and Fessahaie conducted a similar comparison of three 30-degree oblique tests with 50% overlap, and the error in these tests was 34% [5]. In a study comparing delta V with EDR data from NASS cases, crashes with less than 50% overlap had greater error than crashes with more than 50% overlap [6]. There are no studies, however, that have analyzed only small overlap crashes. The purpose of the current study was to quantify the accuracy of reconstructed delta V estimates in small overlap frontal crashes.

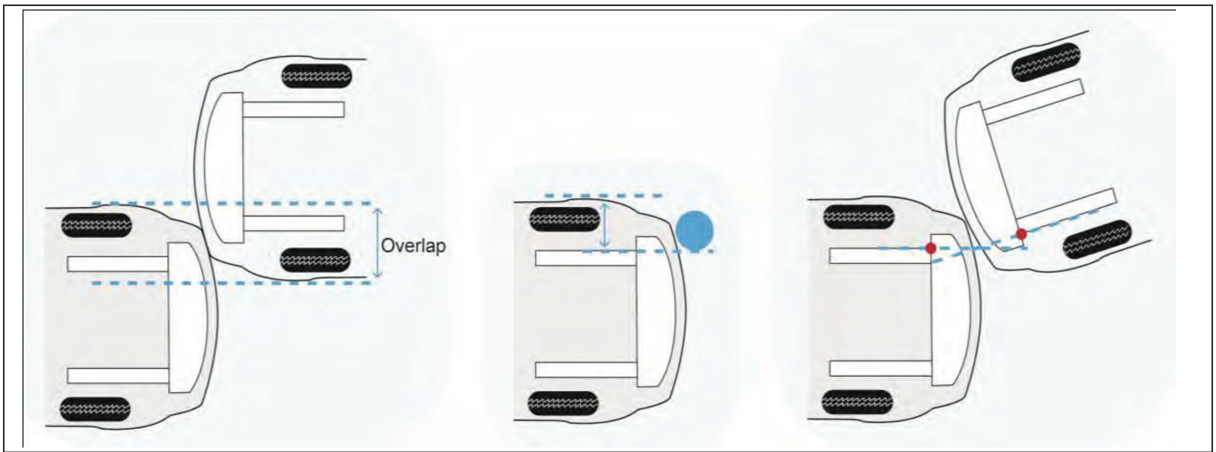
## METHODS

Twelve vehicles were tested in three different small overlap crash configurations (Table 1, Figure 1). Five vehicles were tested using a 254-mm (10-inch) fixed, rigid pole barrier. Overlap percentage was measured to the inboard edge of the pole. Four vehicles were tested using a vehicle-to-vehicle collinear configuration. In the test with two matching vehicles (Ford Taurus), the data were averaged. Overlap percentage was measured to the line representing the maximum width of the opposing vehicle.

Table 1. Test vehicles and configurations

| Test Condition | Vehicle | Crash Partner | Percent Overlap | Test Speed |
|---|---|---|---|---|
| Pole | 2004 Chrysler Concorde[1] | 25.4 cm rigid pole | 25% | 48 km/h |
| | 2008 Honda Accord | 25.4 cm rigid pole | 25% | 64 km/h |
| | 2010 Subaru Forester[2] | 25.4 cm rigid pole | 25% | 64 km/h |
| | 2001 Ford Taurus | 25.4 cm rigid pole | 22% | 56 km/h |
| | 2007 Mitsubishi Galant | 25.4 cm rigid pole | 25% | 64 km/h |
| Vehicle-to-Vehicle Collinear | 2005 Ford Taurus | 2001 Ford Taurus | 28% | 56 km/h |
| | 2008 Ford Fusion[2] | 2009 Mitsubishi Galant | 28% | 64 km/h |
| | 2009 Mitsubishi Galant | 2008 Ford Fusion | 28% | 64 km/h |
| Vehicle-to-Vehicle Oblique | 2002 Ford Taurus | 2001 Ford Taurus | n/a | 56 km/h |
| | 2009 Mitsubishi Galant | 2009 Ford Fusion | n/a | 64 km/h |
| | 2008 Ford Fusion | 2009 Mitsubishi Galant | n/a | 64 km/h |

[1]Bumper cover measurement only
[2]Bumper bar measurement only




| Vehicle-to-Vehicle Collinear | Pole | Vehicle-to-Vehicle Oblique |
|---|---|---|

Figure 1. Diagrams of crash configurations

Three vehicles were tested in a vehicle-to-vehicle oblique test configuration. The path of the striking vehicle was 15 degrees oblique from the path of the case vehicle. An overlap percentage was not calculated in these tests due to the oblique nature. The crash configuration was based on aligning the vehicles so that the target points on each vehicle (intersection of the driver side outboard surface of the longitudinal rail and the rear surface of the bumper bar) would meet at impact (although this would take place after the actual initial contact of the two vehicle bumpers). In these tests, only the case vehicle had small overlap test damage. The striking vehicle had a distributed loading pattern, very similar to that seen in a 40% offset test. The different damage patterns for each vehicle matched the trends seen in the real-world study [3], which led to the identification of this test configuration.

IIHS's crash test facility has parallel, opposing runways, and the angles of the runways are not adjustable. To conduct the oblique tests, a rail system was anchored to the floor just beyond the position where the vehicle is released from the towing mechanism. The rails consisted of two C channel sections, creating a channel that engaged with roller systems mounted to the vehicle underbody. Each rail system had an arc resulting in a final vector 7.5 degrees away from the runway vector. The case vehicle rail system turned to the right, whereas the striking vehicle rail system turned to the left. The resulting alignment at impact is equivalent, with respect to the reference frame of the case vehicle, to the striking vehicle impacting at a 15-degree angle. In addition to the roller systems welded to the vehicle, the steering columns for both vehicles were fixed in a neutral position to improve vehicle tracking after exiting the rail system.

Each vehicle had precrash and postcrash damage measurements of the bumper cover and bumper bar, except for those vehicles noted in Table 1. Where both sets of measures were available, delta V estimates were calculated in two ways: one with damage measured across the bumper cover, and one with crush measurements taken on the face of the bumper bar. WinSMASH was used to calculate delta V estimates, and the reported values are longitudinal delta Vs. Vehicle specific stiffness values were used for all vehicles. The WinSMASH delta V estimates were compared with actual delta V values measured from the vehicle accelerometer (longitudinal axis of vehicle), located at the rear seating area along the centerline of the vehicle floor.

## RESULTS

Selected postcrash images of vehicle damage for each test condition are shown in Figures 2-4. In each case, there was minor longitudinal loading of the frame rail, whereas the components that underwent primary loading included the wheel, suspension components, upper rail, and occupant compartment.

Figure 2. Pole test condition, 2007 Mitsubishi Galant

Figure 3. Vehicle-to-vehicle collinear test condition, 2008 Ford Fusion

Figure 4. Vehicle-to-vehicle oblique test condition, 2002 Ford Taurus

Estimated and actual delta V values for all tests are shown in Table 2. Estimated delta V values under-estimated actual values in all tests. The average error (as a percentage of the actual value) was 50% (24.5 vs. 49.0 km/h). Results did vary by crash configuration. Pole tests had the greatest error (67%), followed by collinear (38%) and oblique (30%). These trends may have been due to the specific test conditions (e.g., overlap values) of the crash configurations. As is typical in crashes that do not engage the full width of the vehicle, actual delta V values were lower than impact speeds in all but one test.

Table 2. Estimated and actual delta V values

| Test Condition | Vehicle | Test Speed (km/h) | Actual Delta V (km/h) | Estimated Delta V (km/h) | Percent Error |
|---|---|---|---|---|---|
| Pole | 2004 Chrysler Concorde[1] | 48 | 48.3 | 22.0 | 54.5% |
| | 2008 Honda Accord | 64 | 58.2 | 15.0 | 74.2% |
| | 2010 Subaru Forester[2] | 64 | 58.1 | 13.0 | 77.6% |
| | 2001 Ford Taurus | 56 | 42.0 | 14.0 | 66.7% |
| | 2007 Mitsubishi Galant | 64 | 59.4 | 24.0 | 59.6% |
| Vehicle-to-Vehicle Collinear | 2005 Ford Taurus | 56 | 34.4 | 20.0 | 41.9% |
| | 2008 Ford Fusion[2] | 64 | 37.6 | 24.0 | 36.2% |
| | 2009 Mitsubishi Galant | 64 | 39.9 | 25.0 | 37.3% |
| Vehicle-to-Vehicle Oblique | 2002 Ford Taurus | 56 | 48.9 | 26.6 | 45.6% |
| | 2009 Mitsubishi Galant | 64 | 57.1 | 46.3 | 18.9% |
| | 2008 Ford Fusion | 64 | 55.3 | 39.4 | 28.8% |
| Average | | 60.4 | 49.0 | 24.5 | 50.0% |

[1]Bumper cover measurement only

[2]Bumper bar measurement only

In several tests, as is the case in many actual NASS investigations, the bumper cover was sufficiently damaged that it could not be measured. Because the bumper cover is not a structural element, its measurements also may be less definitive. For the vehicles that had both bumper cover and bumper bar measures, resulting delta V estimates were compared (Table 3). The average error (as a percentage, measured with respect to the bumper cover) was 6%. There was not a consistent trend as to which set of measurements resulted in higher estimates for delta V.

Table 3. Estimated delta V values using bumper cover and bumper bar crush values

| Test Condition | Vehicle | Estimated Delta V (km/h) Bumper Cover | Estimated Delta V (km/h) Bumper Bar | Percent Error |
|---|---|---|---|---|
| Pole | 2008 Honda Accord | 15.0 | 14.0 | -7% |
| | 2001 Ford Taurus | 14.0 | 15.0 | +7% |
| | 2007 Mitsubishi Galant | 24.0 | 21.0 | -13% |
| Vehicle-to-Vehicle Collinear | 2005 Ford Taurus | 20.0 | 22.0 | +10% |
| | 2009 Mitsubishi Galant | 25.0 | 24.0 | -4% |
| Vehicle-to-Vehicle Oblique | 2002 Ford Taurus | 26.6 | 26.6 | 0% |
| | 2009 Mitsubishi Galant | 46.3 | 46.3 | 0% |
| | 2008 Ford Fusion | 39.4 | 37.4 | -5% |
| Average (absolute value of error) | | | | 6% |

## DISCUSSION

Typical crash reconstruction techniques, and the one most commonly used in NASS, estimate crash severity by measuring vehicle deformation. These measurements are combined with estimates of vehicle stiffness values, usually based on full-width laboratory crash tests, to estimate vehicle delta Vs. The technique also assumes the vehicle front is equally stiff across its entire width, when in fact the structural components that contribute to stiffness values are located at discrete locations. Consequently, when less than the full width of the vehicle front end is engaged, the actual stiffness of the engaged structure may be different from the estimate based on full-width crash testing. Empirical evidence suggests these estimates result in underestimates of actual delta Vs [4, 5, 6]. This error is even greater in small overlap crashes because the energy-absorbing components crushed in flat-barrier tests (bumper cover/bar and their underlying structural members) are largely not loaded and, instead, energy is absorbed by deformation of the suspension system and occupant compartment, which generally is not observed in the crash tests used to estimate stiffness for crash reconstructions. Eleven small overlap crashes, in three different crash configurations, were used to compare estimated delta Vs with actual values. The estimated values significantly underestimate actual delta Vs by an average of 50%.

Small overlap frontal crashes, which are not currently addressed by federal standards or consumer information testing, account for a significant percentage of serious frontal crashes [1, 2]. The configurations and speeds of these real-world crashes must be understood to develop a potential crash test to evaluate vehicle crashworthiness in these types of crashes. A previous NASS study of small overlap crashes resulting in serious driver injury [3] identified the three predominant crash configurations, and the average delta V estimates (for those with estimated values) was 32 km/h (range 17-54 km/h). Based on findings from the current study of delta V estimation error in small overlap crashes, a more realistic estimate of average delta V in the NASS serious injury cases would be 64 km/h (range 34-108 km/h), with a correspondingly higher impact speed. Therefore, consumer information or regulatory small overlap crash tests with an impact speed in the range of approximately 64 km/h would represent a significant portion of such real crashes causing injury and death.

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