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Eleven Instrumented Motorcycle Crash Tests and Development of Updated Motorcycle Impact-Speed Equations

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Abstract

Eleven instrumented crash tests were performed as part of the 2016 World Reconstruction Exposition (WREX2016), using seven Harley-Davidson motorcycles and three automobiles. For all tests, the automobile was stationary while the motorcycle was delivered into the vehicle, while upright with tires rolling, at varying speeds. Seven tests were performed at speeds between 30 and 46 mph while four low-speed tests were performed to establish the onset of permanent motorcycle deformation. Data from these tests, and other published testing, was analyzed using previously published equations to determine their accuracy when predicting the impact speed of Harley-Davidson motorcycles. The most accurate model was the Modified Eubanks set of equations introduced in 2009, producing errors with an average of 0.4 mph and a standard deviation (SD) of 4.8 mph.

An updated set of Eubanks-style equations were developed adding data published since 2009, and further partitioning from two equations (pillars/axles and doors/fenders) to four equations (axles, pillars/bumpers, doors, and fenders). When applied to the subject tests, the newly developed set of equations produced an average error of 3.5 mph (SD = 4.3 mph). With respect to all available data (N = 99), the equations produced an average error of 0.1 mph and an SD of 5.8 mph. The errors were also analyzed for each of the four equations developed here, and confidence intervals offered. This research, which represents the first detailed analysis of Harley-Davidson motorcycles' collision response, indicates they behave in a manner similar to previously tested motorcycles. Further, the equations developed and presented here give accident investigators a refined method for estimating the impact speed of an upright motorcycle, Harley-Davidson or otherwise, having struck an automobile with its front tire.

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Introduction

Analyzing vehicle crush to estimate energy dissipation and thereby calculate vehicle speeds dates back to the 1960s. Jiang et al. [1] provided a thorough summary of the history of speed-from-crush analyses. The earliest work, as well as much of what has come since, focused on passenger cars.

The earliest motorcycle testing was conducted by Severy [2], who used seven Honda motorcycles, including one 90cc-displacement machine tested at 30 mph, five 350cc units at 20, 30, and 40 mph, and one 750cc machine tested at 30 mph. The motorcycles were delivered by dolly such that they struck the side of a stationary 1964 Plymouth sedan in a perpendicular orientation. That research resulted in a linear relationship between approach speed and motorcycle wheelbase reduction. The following equation is the least-squares best-fit line to that data:

$$S = 2.35 \times L + 8.6 \qquad \text{Eq. (1)}$$

where
S is the impact speed (mph)
L is the motorcycle wheelbase reduction (in)

This equation's coefficient of determination (R-squared value) with the seven data points is in excess of 0.97, indicating a near-perfect fit for this limited dataset with the motorcycle perpendicularly striking the door of a stationary automobile. The correlation between wheelbase change and speed is not nearly as strong in later testing. This is likely due to the wider variety of motorcycles and target vehicles used in subsequent testing, where the automobile and motorcycle structures become more diverse, as do the impact configurations.

Grandel and Zeisberger [3] suggested a technique which required conducting multiple exemplar tests. Though such vehicle-specific testing is essentially never feasible for reconstructionists, the article outlined a technique utilizing maximum deformation from both the automobile and motorcycle. Including the energy dissipated in deforming the side of the car, as well as reducing the motorcycle wheelbase, refined the relationship between crush and the motorcycle impact speed.

Adamson et al. [4] reported the results of a series of tests using Kawasaki KZ1000 motorcycles, essentially following Grandel's suggestion of repeatedly testing the same model machine. The tests involved the motorcycles striking either concrete blocks or one of two nearly identical passenger cars at various locations and various speeds. Adamson reported the linear relationship of crush as a function of speed, rather than speed as a function of crush. Inverting that data, and fitting a least-squares line, the onset of permanent crush for the barrier impacts was found to be 5.9 mph, while the onset of permanent wheelbase reduction for the car-side impacts was over 21 mph. Using crush from both vehicles improved the accuracy of the predicted speed compared to simply considering motorcycle crush, reducing the absolute average error from 3.9 to 2.1 mph.

This dataset is the most consistent, by far, in the literature regarding the onset of permanent crush in a particular impact configuration, namely, striking a rigid vertical surface. Not just because the impact partners were rigid and identical but also because the motorcycles were nearly all the same weight.

Adamson's 5.9 mph intercept on the barrier speed versus crush chart is slightly lower than that observed by Severy (8.6 mph), and is significantly lower than has been observed in subsequent analyses involving passenger cars. This suggests Severy's 1964 passenger cars were more stiff than the cars used by Adamson. The 21-22 mph onset of permanent crush when striking the side of a stationary vehicle is significantly higher than observed elsewhere, highlighting that the nature of the struck object or vehicle is important to the analysis.

Deyerl and Cheng [5] demonstrated the use of EDSMAC4 to model the crashes reported by Adamson et al. In order to match the automotive damage profiles, the authors had to increase the stiffness coefficients by up to 300% over the nominal A and B values at different areas of the target vehicles. Warner [6] reported on the local effect of vehicle stiffness variations, as related to narrow object (pole) impacts, finding that the front axle and A-pillar locations sustained roughly half the crush when compared to center-of-gravity and B-pillar locations for the same amount of energy dissipated. This is consistent with Deyerl's observations regarding car stiffness during motorcycle impacts. Given the same crush width, if the stiffness coefficients increase by 300%, the crush depth necessary for the same energy dissipation goes down by 58%. This indicates local stiffness values at the area of impact must be considered when using crush deformation to assess energy.

In 2009, Bartlett [7] evaluated motorcycle impacts based on location, grouping door panel and fender strikes together for analysis and collisions within a foot of an axle or at a pillar into another group. The best relationships were found using a Modified Eubanks-form equation, which utilized the total crush of both vehicles added together, where total crush is defined as the wheelbase reduction sustained by the motorcycle and maximum automotive deformation [8]. Those equations, with Bartlett's modified coefficients, took the following form:

Eubanks form with Door/Fender Coefficients:

$$S = 1.45 \times \left(L + C\right) + 10.12 \qquad \text{Eq. (2)}$$

Eubanks form with Pillar/Axle Coefficients:

$$S = 1.59 \times \left(L + C\right) + 14.72 \qquad \text{Eq. (3)}$$

where
S is the impact speed (mph)
L is the motorcycle wheelbase reduction (in)
C is the maximum automotive deformation (in)

The same year Bartlett's analysis appeared, Wood [9] proposed an energy technique that was later refined in a trio of 2014 papers, using a larger dataset. One of these articles incorporated a force balance, concluding that the closing speed could be estimated using one equation, without distinction of what portion of the automobile was struck [10]. Another 2014 paper authored by Glynn and Wood [11] describes the refinement of the technique to accommodate cases where only motorcycle or automotive deformation are known. In these equations, coefficients were implemented to account for soft and hard impact areas.

One limitation of any motorcycle crush analysis is its inherent insensitivity at higher speeds. After the front wheel and fork have collapsed to the frame and engine block, there is little additional motorcycle deformation possible. Similarly, the mass of the automobile and eccentricity of the collision, with respect to the automobile center of gravity, will affect the maximum possible target vehicle crush depth. This concern is addressed in the Wood technique by the use of the equivalent car mass, which incorporates the impact eccentricity.

In 2010, Searle [12] proposed a theoretical technique which utilized empirically derived coefficients for automotive and motorcycle stiffness. This technique offered the benefit of not requiring the analyst to assess soft or hard impact areas, but did require some specific information about the orientation and location of the collision. Using the Searle technique, Bartlett showed in 2014 that an improved relationship was possible with a modified motorcycle stiffness coefficient [13].

While a great deal of study has been conducted in an effort to establish a method for determining motorcycle impact speed, no such study has been performed involving Harley-Davidson motorcycles. With nearly five million motorcycles sold in the last 20 years, Harley-Davidsons are ubiquitous, making it important to understand and account for their collision response [14]. Additionally, none of the currently developed equations account for the totality of available crash data. Considering these shortages, seven crash tests involving Harley-Davidson motorcycles were performed, and the data was analyzed, in conjunction with all known data, to arrive at updated motorcycle impact-speed equations.

Procedure

Eleven instrumented crash tests were performed as part of the WREX2016. Seven Harley-Davidson motorcycles and three automobiles were utilized (see Table 1). For all tests, the automobile was stationary while the motorcycle was delivered at varying speeds. Seven of the tests were performed at speeds between 30 and 46 mph while four low-speed tests were performed to establish the onset of permanent motorcycle deformation.

All vehicles were prepared for testing by draining coolant and engine oil and inflating tires to the manufacturer recommended pressure. In addition, drive belts and chains were removed from all motorcycles to reduce drag. The vehicles were photographed and weighed using digital scales (Intercomp 170183, Medina, MN), as shown in Figure 1. Three-dimensional scans of all automobiles were created using a ScanStation P30 (Leica, San Ramon, CA), while the initial wheelbase of each motorcycle was measured using a tape measure and plumb bob. To do so, the distance between the axles was measured on the left and right sides of the motorcycle, and those values were averaged. The diameter of the inner fork tubes of each motorcycle was also measured using dial calipers.

Low-Speed Testing

A 2002 Harley-Davidson Sportster (M5) was propelled into the rear bumper of a 2006 Nissan Maxima (C1) at increasing speeds until notable, permanent motorcycle wheelbase reduction was measured, using a tape measure and plumb bob. The speed of the motorcycle was monitored and recorded using a 20 Hz VBOX Sport GPS transponder (Racelogic, Farmington Hills, MI), which was solidly mounted to the rear fender using self-tapping screws and a custom enclosure.

Full-Speed Testing

A custom fixture was designed for the subject testing (North Coast Truck Inspection, Forestville, CA), and was constructed of welded tubular steel in a configuration suitable for mounting to the frame of the available push vehicle, a 2001 Chevrolet Silverado (see Figure 2). The fixture connected to a one-inch, square tubular steel crossmember that was welded laterally to the back of the motorcycle's forward frame downtubes. The fixture captured the crossmember, prohibiting rearward movement but allowing forward movement, and was designed with sufficient roll and yaw compliance to allow the motorcycle to achieve its stable rolling state. When the desired path and speed were achieved, the motorcycle was released by braking the push vehicle.

The VBOX Sport was installed on the rear fender or fuel tank, depending on configuration and available space, of each motorcycle prior to testing. The VBOX Sport recorded

TABLE 1 Details of motorcycles and automobiles used during the subject tests.

ID	Make	Model	Year	Color	Weight (lbs)
M1	H-D	Softail Breakout	2013	Red	667
M2	H-D	Dyna Street Bob	2013	Blue	633
M3	H-D	Dyna Fat Bob	2012	Black	678
M4	H-D	Dyna Low Rider	2012	Blue	649
M5	H-D	Sportster 883	1997	Black	498
M6	H-D	Sportster 883	2002	Purple	500
M7	H-D	Sportster 883	2003	Black	483
C1	Nissan	Maxima	2006	Brown	3,449
C2	Dodge	Durango	2005	Blue	4,740
C3	Hyundai	Sonata	2006	Silver	3,547

the entire speed trace of the motorcycle prior to impact, allowing for confident determination of impact speed (see Figure 3). Speed traps were used to verify impact speed (Polaris Multi-Event Timer, FarmTek, Inc., Wylie, TX), and a VBOX Video HD2 system was mounted to the push vehicle for further confirmation of the VBOX Sport data. In addition, a 3.2 kHz, ± 200*g* MEMS accelerometer was mounted to each motorcycle as close to the center of gravity as practicable (Slam Stick C, Midé, Medford, MA).

With respect to the automobiles, the center consoles of each vehicle were removed and a 3.2 kHz, ± 200*g* MEMS accelerometer was mounted near the center of gravity. A Vericom VC4000DAQ accelerometer was also mounted to the windshield of each target vehicle (Vericom, LLC, Rogers, MN). None of the target vehicle event data recorders (EDRs) had the ability to capture lateral events, so EDR data was not recorded.

After instrumentation was installed, the automobile was parked perpendicular to the motorcycle's approach direction, and its location was documented using a total station (Leica TS-02 and TS-12, San Ramon, CA). Several real-time and high-speed video cameras were set to record the impact. The postimpact locations of the automobile and motorcycle were both documented via total station, and the postimpact motorcycle wheelbase was measured. Photographs of the motorcycle and automobile were taken shortly after impact, and again once the vehicles were separated. After all tests were complete, three-dimensional measurements of the damaged automobiles were created using the Leica ScanStation.

Data Processing

The pre and post-impact 3D point clouds of each automobile were compared using CloudCompare to establish the maximum crush sustained during each test [15]. As discussed by Erickson et al., CloudCompare implements an Iterative Closest Point algorithm, where the position and orientation of each point cloud is varied until the point-to-point distance is minimized [16]. This methodology eliminates any subjectivity and allows for straightforward statistical analysis, since the results of the process are reported, including the cloud-to-cloud point distance, and can be exported as a CSV file for identification of the maximum distance between point clouds (Figures 4 and 5).

Results

Low-Speed Testing

At an impact speed of 7.1 mph, the front suspension of the Harley-Davidson Sportster (M5) compressed fully and flexed backward allowing the front fender to contact a regulator attached to the leading portion of the frame (see Figure 6). However, no notable permanent wheelbase reduction was measured. Similar behavior was noted at impact speeds of 9.2

FIGURE 1 2013 Harley-Davidson Softail Breakout (M1) prepared for testing and being weighed using digital scales.

FIGURE 2 2013 Dyna Street Bob (M2) attached to the custom delivery system.

FIGURE 3 Example of motorcycle speed trace acquired from VBOX Sport mounted to the rear of M1 during Test 3. Note the decrease in speed as the motorcycle releases from the delivery system (9.5 s), and subsequent increase as the rear of the motorcycle rotates upward upon impact (11.8 s).

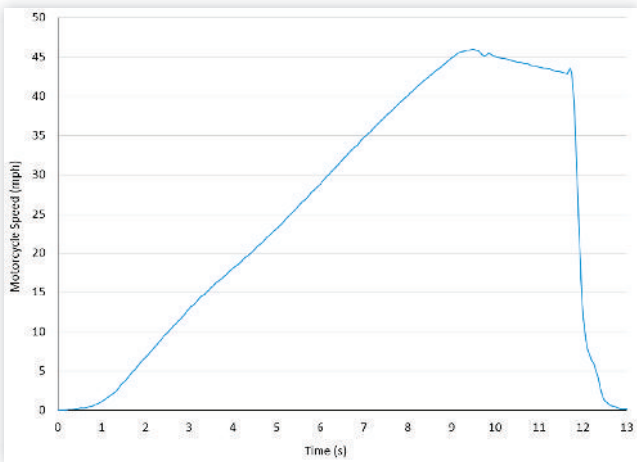
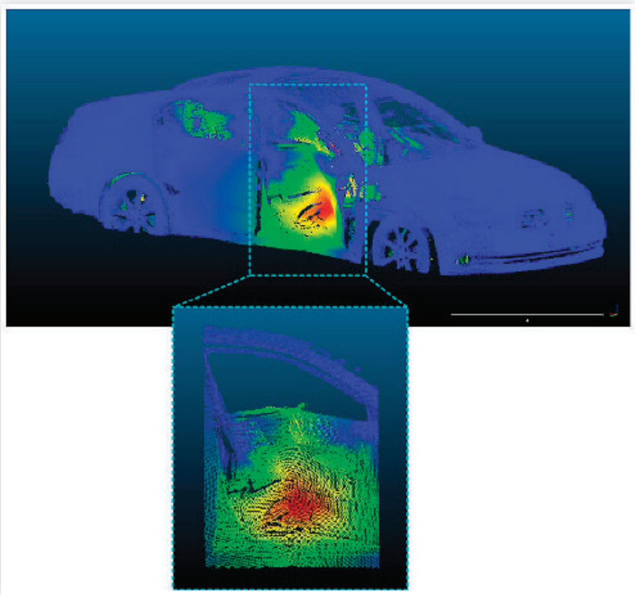


FIGURE 4 Upper image: postimpact 3-D scan data of the 2006 Nissan Maxima (C1). Lower image: compilation of pre- and post-impact scan data, merged using CloudCompare.

FIGURE 5 Color-coded output from CloudCompare, showing the distance between the pre- and post-impact point clouds, where blue is the shortest distance and red is the largest.



and 11.0 mph. At an impact speed of 13.5 mph, permanent wheelbase reduction of one inch was measured.

Full-Speed Testing

A summary of the results is presented in Table 2. The test identification numbers (IDs) were retained from the WREX conference proceedings to allow attendees and others in possession of the data to cross-reference here without issue.

Test 3: Harley-Davidson into Nissan Right Front Door

A 2013 Harley-Davidson Softail Breakout (M1) was delivered into the right front door of a stationary 2006 Nissan Maxima (C1) at a speed of 43.0 mph, resulting in a wheelbase reduction of 11.3 in. and maximum crush to the Nissan of 18.7 in., for a total of 30.0 in. of crush (wheelbase reduction and maximum crush combined) (Figure 7).

The inner fork tubes were bent backward, below the lower triple clamp, and deformed at the junction with the triple clamp, but not torn, as shown in Figure 8. The trailing portion of the front wheel was flattened as it was forced backward into the leading structure of the frame. Additional photographs of the damage to both vehicles can be found in Appendix A.

Test 5: Harley-Davidson into Nissan Left Rear Door

A 2013 Harley-Davidson Dyna Street Bob (M2) was delivered into the left rear door of a stationary 2006 Nissan Maxima (C1) at 36.9 mph, resulting in a wheelbase reduction of 12.8 in. and maximum crush to the Nissan of 8.6 in., for a total of 21.4 in. of crush. Figures 9 and 10 show the postimpact condition of the two vehicles.

The inner fork tubes of M2 were damaged in a manner similar to M1 of Test 3. Again, the fork tubes were deformed but not torn. Both the forward and trailing portions of M2's spoked front wheel were crushed, and as a result, the brake disk contacted the door panel of C1 generating a distinct narrow, vertical area of compression and abrasion. Additional photographs of both vehicles are included in Appendix A.

Test 8: Harley-Davidson into Dodge's Left Rear Quarter Panel

A 2012 Harley-Davidson Dyna Fat Bob (M3) was delivered into the left rear of a 2005 Dodge Durango (C2) at 46.3 mph. The Dodge's postimpact condition is shown in Figure 11, with a maximum crush of 9.1 in. The motorcycle suffered broken components in the front end, with a documented wheelbase reduction of 3.3 in. However, the wheel could be moved with respect to the frame, due to the damage, making the documented wheelbase reduction irrelevant.

M3 contacted the rear tire of the Dodge and the left fork inner tube fractured during the impact, allowing the front wheel assembly to rotate approximately 90° counterclockwise, while the right inner tube only sustained minimal damage as shown in Figure 12. Due to the nature of the damage, this test was not included in the development of the equations that follow.

Test 11: Harley-Davidson into Dodge's Right Front Door

A 2012 Harley-Davidson Dyna Low Rider (M4) was delivered into the right front door a 2005 Dodge Durango (C2) at 42.9 mph, resulting in a wheelbase reduction of 10.7 in. and maximum crush to the Dodge of 10.3 in., for a total of 21.0 in. of crush. The Dodge's damage is shown in Figure 13.

The left inner fork tube of M4 was partially torn during the test, with the leading portion failing and the remainder staying intact, as shown in Figure 14. The trailing portion of the front wheel was deformed and the left side of the rim was fractured. While the front of M4 primarily came into contact with the leading portion of the right front door, the tire did contact the adjacent portion of the Dodge's frame. In addition, the right side of the one-inch square-tube crossmember, attached to the motorcycle for delivery, contacted the Dodge during the test. However, the contact was not substantial enough to bend the tube. Additional photographs of both vehicles are included in Appendix A.

FIGURE 6 Example of low-speed test impact configuration and behavior. Here, first contact and maximum engagement are shown for the 7.1 mph test. Notice the trailing edge of the front fender is contacting the leading portion of the frame and the rear tire is lifted off the ground.

Test 22: Harley-Davidson into Hyundai's Right Rear Wheel

A 1997 Harley-Davidson Sportster 883 (M5) was delivered into the right rear tire area of a 2006 Hyundai Sonata (C3) at 30.3 mph. Figures 15 and 16 show the postimpact damage to both vehicles. M5 sustained a wheelbase reduction of 4.3 in., while the Hyundai sustained a maximum crush of 2.1 in., for a total of 6.4 in. of crush.

The front tire of M5 contacted the aft portion of the Hyundai's right rear wheel and the adjacent portion of the tire. Subsequent contact involved the right extension of the rear bumper cover and the quarter panel. There was evidence of notable contact on the wheel within 6 in. of the axle, and the suspension was damaged, causing the wheel to be askew.

The inner fork tubes of M5 were bent, but did not display any substantial, concentrated areas of deformation as observed in the higher speed tests (3, 5, and 11). The rear

TABLE 2 Summary of full-speed tests where MC identifies the involved motorcycle, TV identifies the involved target vehicle, L is the wheelbase reduction, and C is the maximum deformation to the target vehicle.

ID	MC	TV	Imp. location	V_{Imp} (mph)	L (in)	C (in)	Total crush (in)
3	M1	C1	RF door	43.0	11.3	18.7	30.0
5	M2	C1	LR door	36.9	12.8	8.6	21.4
8	M3	C2	LR	46.3	3.3	9.1	12.4
11	M4	C2	RF door	42.9	10.7	10.3	21.0
22	M5	C3	RR axle	30.3	4.3	2.1	6.4
23	M6	C3	RR door	42.7	8.8	7.1	15.9
24	M7	C3	LR door	35.5	8.9	4.2	13.1

FIGURE 7 Right-side view of C1 showing the impact damage sustained during Test 3, where the maximum crush was 18.7 in.

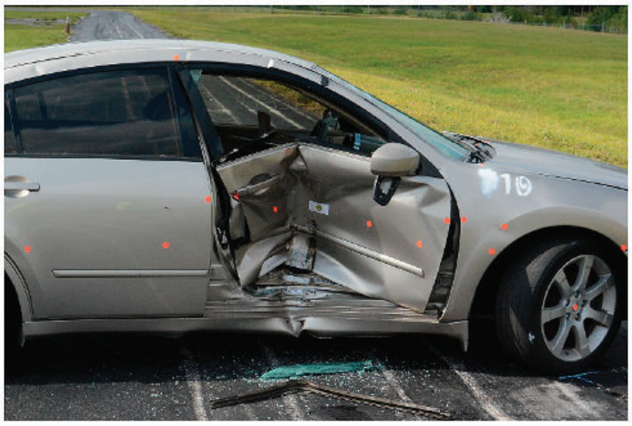


FIGURE 8 Right-side view of M1 showing damage sustained during Test 3, where the wheelbase reduction was 11.3 in.

FIGURE 9 Left-side view of C1 showing the impact damage sustained during Test 5, where the maximum crush was 8.6 in.

FIGURE 10 Left-side view of M2 showing damage sustained during Test 5, where the wheelbase reduction was 12.8 in.

FIGURE 11 Left rear view of C2 showing damage sustained during Test 8, where the maximum crush was 9.1 in.

FIGURE 12 Left-side view of M3 showing damage sustained during Test 8, where the documented wheelbase reduction was 3.3 in.

FIGURE 13 Right-side view of C2 showing damage sustained during Test 11, where the maximum crush was 10.3 in.

FIGURE 14 Left-side view of M4 showing damage sustained during Test 11, where the documented wheelbase reduction was 10.7 in.

portion of the motorcycle front fender contacted trailing components, and distinct resultant abrasions and scratches were observed. The front wheel was undamaged. Additional photographs of both vehicles are included in Appendix A.

Test 23: Harley-Davidson into Hyundai's Right Rear Door

A 2002 Harley-Davidson Sportster 883 (M6) was delivered into the right rear door of a 2006 Hyundai Sonata (C3) at 42.7 mph, resulting in a wheelbase reduction of 8.8 in. and a maximum crush to the Hyundai of 7.1 in., for a total of 15.9 in. of crush, as shown in Figures 17 and 18.

Similar to Test 22, the inner fork tubes of M6 were bent, but did not display any substantial, concentrated areas of deformation as observed in the higher speed tests (3, 5, and 11). The forks were also twisted, and the spoked wheel exhibited deformation on the leading and trailing regions. The rear of the front fender was forced backward into the adjacent portion of the frame, compressing and scratching the fender. Additional photographs of the vehicles are included in Appendix A.

FIGURE 15 Right rear view of C3 showing damage sustained during Test 22, where the maximum crush was 2.1 in.

FIGURE 16 Right-side view of M5 showing damage sustained during Test 22, where the documented wheelbase reduction was 4.3 in.

FIGURE 17 Right-side view of C3 showing damage sustained during Test 23, where the maximum crush was 7.1 in.

FIGURE 18 Right-side view of M6 showing damage sustained during Test 23, where the documented wheelbase reduction was 8.8 in.

Test 24: Harley-Davidson into Hyundai's Left Rear Door

A 2003 Harley-Davidson Sportster 883 (M7) was delivered into the left rear door of a 2006 Hyundai Sonata (C3) at 35.5 mph, resulting in a wheelbase reduction of 8.9 in. and maximum crush to the Hyundai of 4.2 in., for a total of 13.1 in. of crush (Figures 19 and 20).

The inner fork tubes of M7 deformed as expected, in a manner similar to that documented in Tests 23 and 24, with gradual deformation and no areas of concentrated deformation or tearing. However, the left outer fork tube fractured in the area between the caliper mounting bolts. The spoked wheel was distorted substantially, compressing between the body of the Hyundai and the leading portion of the Harley-Davidson frame. Additional photographs are including in Appendix A.

In addition to the tests detailed above, four tests involving Harley-Davidson motorcycles conducted at ARC-CSI 2016 were analyzed. In three of the tests, the motorcycles were directed into the side of an automobile, and in the remaining test the motorcycle was directed perpendicularly into a concrete barrier. The vehicles used in that testing are listed below (Tables 3 and 4).

FIGURE 19 Right-side view of C3 showing damage sustained during Test 24, where the maximum crush was 4.2 in.

FIGURE 20 Right-side view of M7 showing damage sustained during Test 24, where the documented wheelbase reduction was 8.9 in.

The impact speeds for the ARC-CSI testing varied between 25.6 and 32.8 mph, with a minimum total crush of 7.2 in., during the barrier impact, and a maximum total crush of 14.1 mph. A summary of the results is shown below.

Data Analysis

The data obtained during the WREX2016 and ARC-CSI crash tests were analyzed using each of the models detailed in the Introduction, and statistical analyses were performed to determine the accuracy of each model, with respect to the subject Harley-Davidson data. The results are detailed below, in chronological order of each model's introduction.

Severy (1970)

As discussed, the Severy equation developed in 1970 only considers the wheelbase reduction to the motorcycle. The average error between the Severy model and the subject Harley-Davidson data was –7.7 mph, meaning the model underestimated the actual impact speed. The SD of the errors was 5.4 mph. A graphical representation of the fit is shown below (Figure 21).

Adamson (2002)

Adamson offered two techniques, one that only considers the motorcycle's wheelbase reduction and another that considered both wheelbase reduction and the maximum crush to the target vehicle. For the former, the average error was 5.9 mph, meaning the model overestimates impact speed, and the SD was 5.4 mph. Figure 22 depicts the fit (Figure 23).

The average error between the predicted and actual impact speed was reduced to 2.6 mph when both the wheelbase reduction and maximum crush were considered, and the SD of the errors was also reduced to 4.6 mph.

Bartlett (2009)

As discussed above, Bartlett's 2009 model, a modified version of Eubanks' 1991 equation, not only accounted for wheelbase reduction and maximum vehicular crush but also considered what portion of the target vehicle was contacted by the motorcycle. Two

TABLE 3 Motorcycles and automobiles used during the ARC-CSI 2016 testing.

ID	Make	Model	Year	Weight (lbs)
A	H-D	Sportster XL 1200C	2006	579
C	H-D	Softail FLSTC	2011	748
D	H-D	Road King FLHRC	2011	794
E	H-D	Electra Glide FLHTCU	2011	881
V	Volks.	Passat	2012	3360
F	Ford	Crown Vic	2011	4057

TABLE 4 Summary of the ARC-CSI 2016 Harley-Davidson testing results.

ID	MC	TV	Imp. location	V_{imp} (mph)	L (in)	C (in)	Total crush (in)
1	A	Barrier	N/A	25.6	7.2	N/A	7.2
3	D	VW	Wheel	31.9	5.0	6.2	11.2
5	E	VW	Pillar	29.0	6.5	2.7	9.2
9	C	Ford	Fender	32.8	3.8	10.3	14.1

FIGURE 21 WREX2016 and ARC-CSI 2016 data compared to the Severy model.

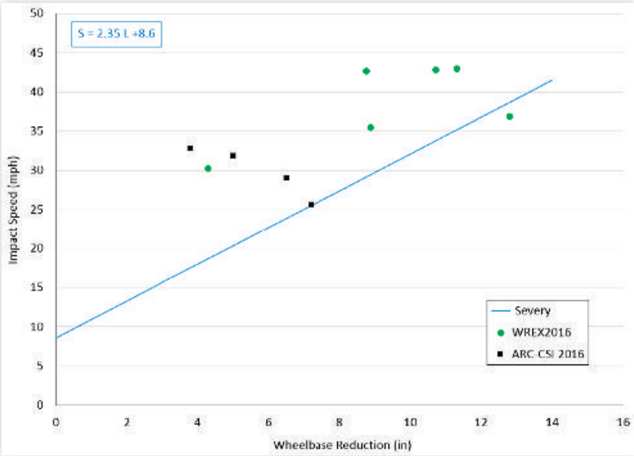
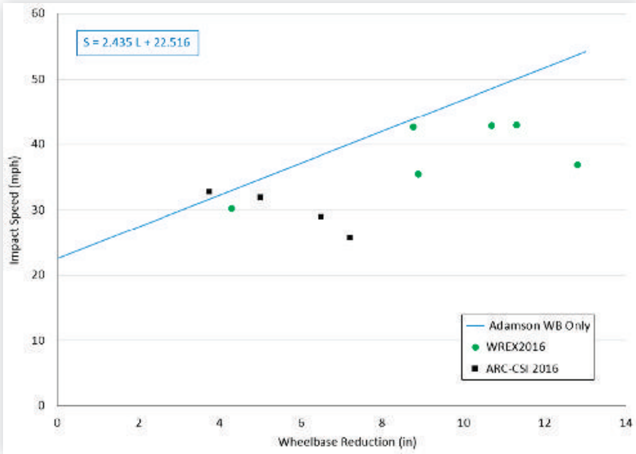


FIGURE 22 WREX2016 and ARC-CSI 2016 data compared to the Adamson wheelbase-only model.



equations resulted, one for pillars and axles and one for doors and fenders. When the subject Harley-Davidson data was analyzed using these equations, the average error was 0.4 mph and the SD was 4.8 mph (Figure 24).

Wood (2014)

Wood's 2014 model incorporated the weights of the motorcycle and automobile as well as wheelbase reduction and maximum crush to the target vehicle. When compared to the subject Harley-Davidson data, the average error was 1.6 mph and the SD was 6.7 mph. The impact speed predicted by the Wood model is shown versus the actual impact speed in Figure 25 where a perfect prediction would result in a data point falling on the 1:1 line.

Glynn (2014)

Glynn developed equations in 2014 that aim to predict closing speed using only the maximum crush sustained by the automobile ***or*** the motorcycle's wheelbase reduction,

FIGURE 23 WREX2016 and ARC-CSI 2016 data compared to the Adamson total crush model.

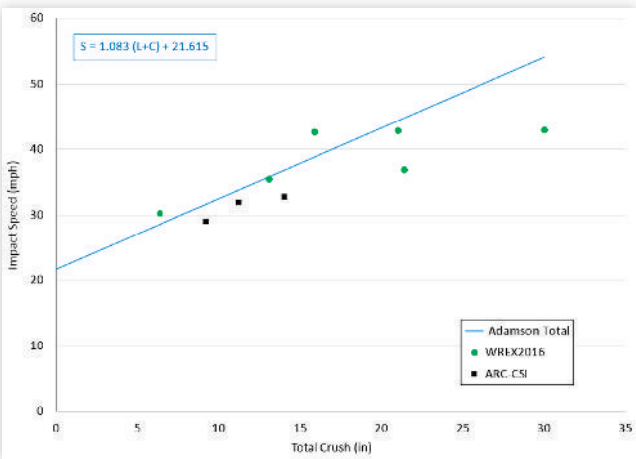


FIGURE 24 WREX2016 and ARC-CSI 2016 data compared to Bartlett's Modified Eubanks model.

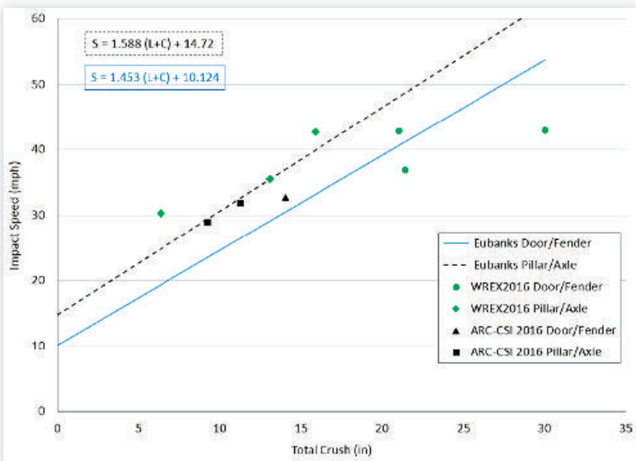


FIGURE 25 WREX2016 and ARC-CSI 2016 data compared to Wood's 2014 model.

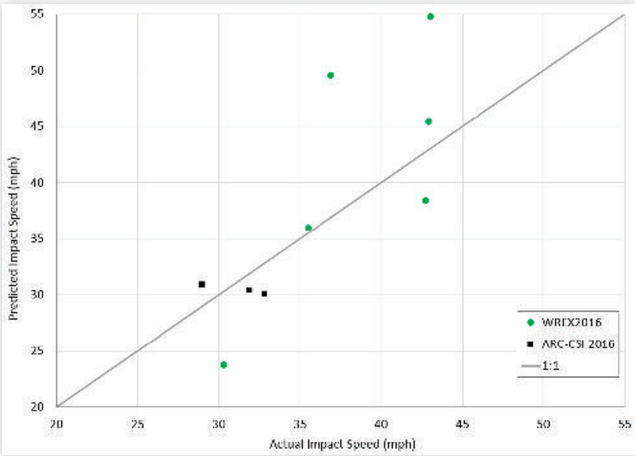
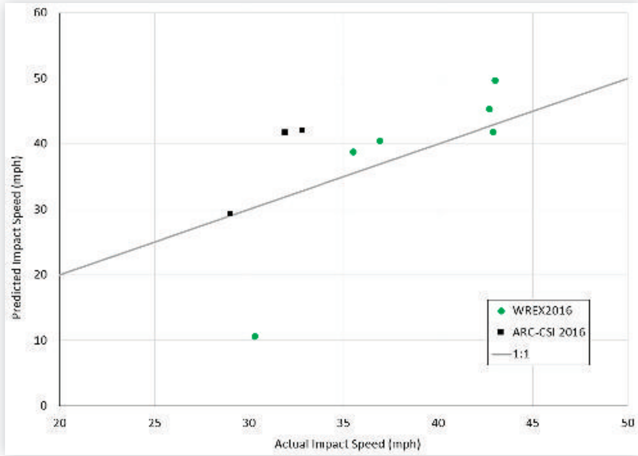


FIGURE 26 WREX2016 and ARC-CSI 2016 data compared to Glynn's car-alone model.



referred to as car alone and motorcycle alone, respectively. The equation is more complex than those presented above and considers the automobile's radius of gyration, the impact lever arm with respect to the automobile's center of gravity, the mass of both vehicles, wheelbase reduction, and the maximum crush sustained by the automobile. When compared to the subject Harley-Davidson data, the average error for the car-alone model was 1.7 mph (overestimated impact speed) with an SD of 8.8 mph (Figure 26).

For the motorcycle-alone model, the average error was 6.9 mph (overestimated impact speed) and the SD was 6.2 mph, meaning the model overpredicted the impact speed. A graphical representation of the fit is shown in Figure 27.

Bartlett/Searle (2014)

In 2014, Bartlett modified Searle's 2010 model by increasing the motorcycle stiffness by approximately 30% and discussed the result. Applying this modified model to the subject data resulted in an average error of –5.7 mph with an SD of 7.9 mph, meaning the model generally underestimated the actual impact speed, as shown in Figure 28.

Table 5 summarizes the average error and SD for each model, and shows that Bartlett's modified Eubanks equations fit the subject data best.

FIGURE 27 WREX2016 and ARC-CSI 2016 data compared to Glynn's motorcycle-alone model.

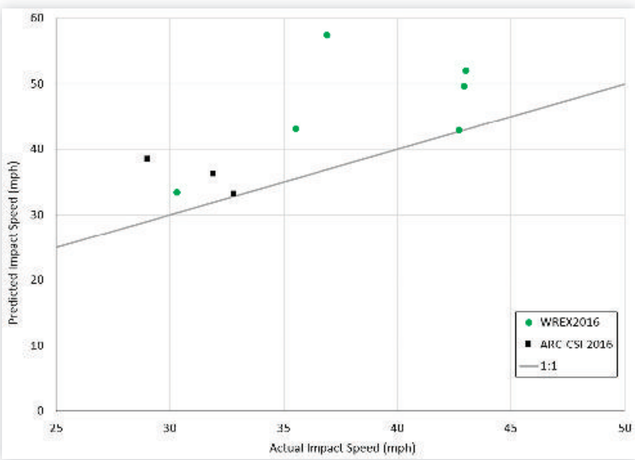


FIGURE 28 WREX2016 and ARC-CSI 2016 data compared to the modified Searle model.

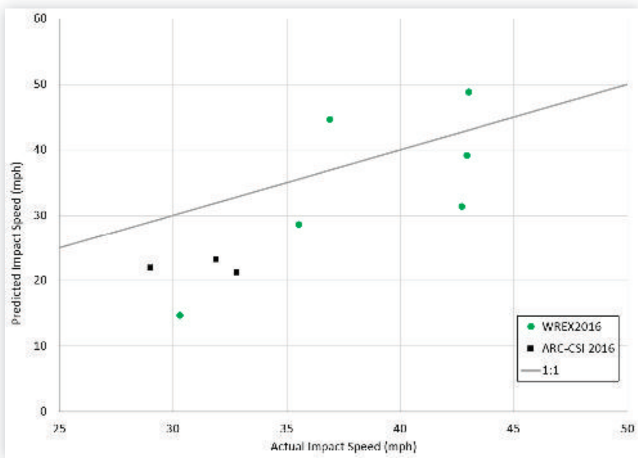


TABLE 5 Statistical summary of each model's fit relative to the subject Harley-Davidson data.

Model	Avg. error (mph)	SD (mph)
Severy	−7.7	5.4
Adamson WB	5.9	5.4
Adamson Total	2.6	4.6
Mod. Eubanks	0.4	4.8
Wood	1.6	6.7
Glynn Car	1.7	8.8
Glynn MC	6.9	6.2
Mod. Searle	−5.7	7.9

Bartlett's modified version of Eubanks equation was developed in 2009. Since then, many additional crash tests have been performed. In addition, Bartlett later determined that if a motorcycle struck a car more than six inches from the axle itself, the automobile wheel's flexibility significantly reduced the automobile's stiffness, changing the deformation behavior. Accounting for this discovery and incorporating new data (all data included in Appendix B), new equations in the form of the Modified Eubanks equation were developed. The equations were developed using all known data, including the subject Harley-Davidson data, and included tests performed using motorcycles equipped with upside-down (USD) forks.

Four equations, based on the involved portion of the target automobile, resulted. The equations are for axles, bumper/pillars, doors, and fenders (also includes quarter panels), and will be referred to as the Modified Bartlett Equations (MBEs).

$$\text{Axle:}\quad S = 2.16\times\left(L+C\right)+17.33 \qquad \text{Eq. (4)}$$

$$\text{Bumper/pillar:}\quad S = 1.36\times\left(L+C\right)+19.50 \qquad \text{Eq. (5)}$$

$$\text{Door:}\quad S = 1.50\times\left(L+C\right)+9.27 \qquad \text{Eq. (6)}$$

$$\text{Fender:}\quad S = 1.26\times\left(L+C\right)+22.95 \qquad \text{Eq. (7)}$$

The fits between these equations and the foundational data used to create them are shown in Figures 29 through 32, including 68% and 95% confidence intervals shown in blue and red, respectively.

FIGURE 29 Test data vs. the MB axle equation including 68% and 95% confidence intervals.

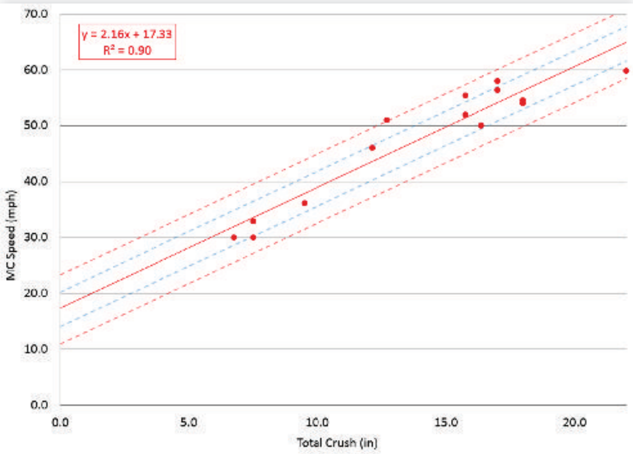


FIGURE 30 Test data vs. the MB bumper/pillar equation including 68% and 95% confidence intervals.

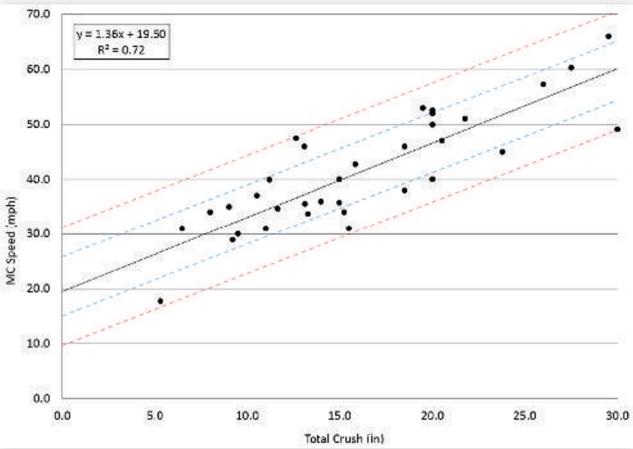


FIGURE 31 Test data vs. the MB door equation, including 68% and 95% confidence intervals.

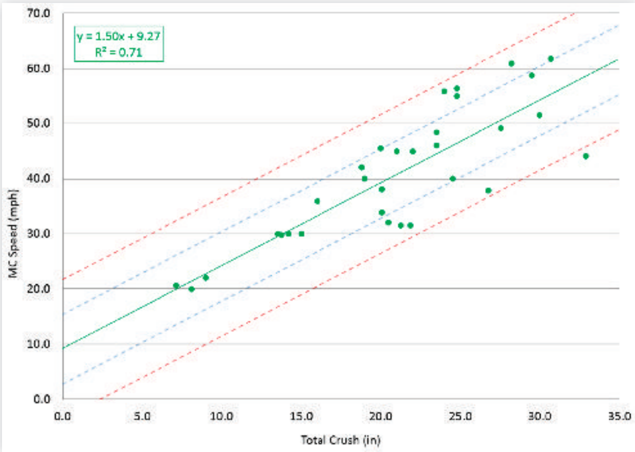
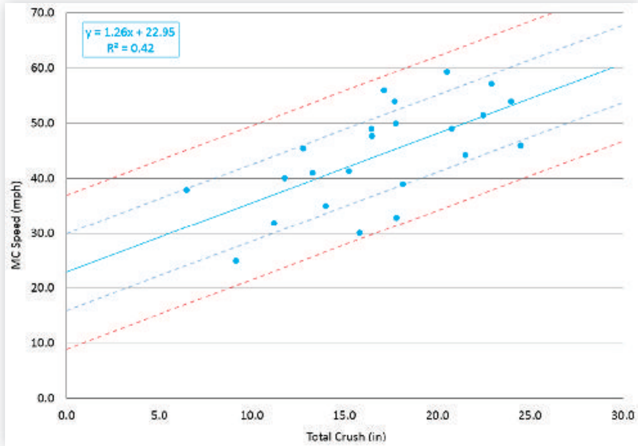


FIGURE 32 Test data vs. the MB fender equation including 68% and 95% confidence intervals.



When compared to the subject Harley-Davidson data, the average error of the MBEs was 3.5 mph with an SD of 4.3 mph. While the Modified Eubanks equations performed slightly better when predicting the Harley-Davidson impact speeds, the MBEs are improved when the total available dataset is considered. Specifically, for all data, the average error of the Modified Eubanks equation is –3.8 mph with an SD of 7.5 mph, while the error for the MBEs is 0.1 mph with an SD of 5.8 mph. The average error and SD for each of the four MBEs is shown in Table 6.

Discussion

Eleven instrumented crash tests were performed as part of WREX2016, seven of which were analyzed with previously developed models, and the efficacy of each model was evaluated. In addition, a new set of equations was developed incorporating all known data, including the subject tests.

The Modified Eubanks equation performed best when predicting the impact speeds of the Harley-Davidsons used in the subject and ARC-CSI testing. The newly developed MBEs also performed well when predicting the Harley-Davidson impact speeds. While no publicly available impact-response testing was available using Harley-Davidsons prior to this study, it was expected that their behavior would align with other motorcycles due to their similar construction, and the subject research has shown that to be true. Considering this, while the Modified Eubanks equations were slightly more accurate when predicting the impacts speeds of the Harley-Davidsons here, the MBEs are based on substantially more data. For this reason, it is recommended that the analyst use the MBEs for analyzing any collision involving a motorcycle equipped with traditional forks, including Harley-Davidsons.

TABLE 6 Average error and SD for each of the MB equations.

Equation	Avg. error (mph)	SD (mph)	51% (mph)	68% (mph)	95% (mph)
Axle	0.2	3.1	−2.4, +2.0	−3.3, +2.9	−6.4, +6.0
Bumper/pillar	0.1	5.4	−3.9, +3.7	−5.5, +5.3	−10.9, +10.7
Door	0.2	6.3	−4.6, +4.2	−6.5, +6.1	−12.8, +12.4
Fender	0.0	7.0	−4.9, +4.9	−7.0, +7.0	−14.0, +14.0

USD forks are substantially different from traditional forks, which provide the vast majority of data feeding current equations. Only three documented tests involving motorcycles equipped with USD forks are available at this time. Two of those are included in the source data used to create the MBEs, while the third was omitted because the motorcycle struck the bumper of a vehicle. Further discussion on bumper impacts is presented below. For these two USD-fork tests, the data fit well with that of the traditional fork. However, additional testing and analysis is desired to determine how confident an analyst can be when establishing impact speed for motorcycles equipped with USD forks, which are so stiff that they commonly fracture in a manner that traditional forks do not. When components are broken, such as steering heads, triple clamps, axle mounts, and inner fork tubes, the MB model, predicated on bending forks to dissipate energy, may not model the collision well.

The available bumper tests (N 10) generally aligned well with the pillar data ($N = 25$), only slightly changing the predicted onset of permanent damage and slope. However, one test was a notable outlier, involving a 2008 Kawasaki ZX600 equipped with USD forks. The motorcycle struck the central portion of a 2001 Cadillac Deville front bumper at 44.9 mph and sustained a wheelbase reduction of 6.9 inches, while the Cadillac only exhibited one inch of crush, for a total of 7.9 in. of crush. The MBEs predicted an impact speed of 19.5 mph for an error of –25.4 mph. In this test, the frame spars behind the steering stem were buckled, and this forced the lower portion of the forks forward, reducing the measured wheelbase reduction. This illustrates an important concept: if the nature of the damage to a motorcycle does not align with that assumed in the model (namely, bending fork-tubes absorbing energy), results may vary from the model predictions. Special care should be taken when evaluating impacts involving motorcycles equipped with USD forks, especially when striking stiff areas of an automobile, or when there are unusual types of damage, such as buckled frame spars, fractured triple clamps, and broken fork legs.

As shown above, the onset of permanent deformation to the forks of the tested 2002 Harley-Davidson Sportster (M5) occurred at an impact speed of 13.5 mph, while no notable deformation was measured at an impact speed of 11.0 mph. This indicates the damage onset speed for such a motorcycle is somewhere between 11.0 and 13.5 mph. When all data is considered, the y-intercept of the MBEs, which represents the onset of permanent deformation, is generally higher. This is thought to be a result of variation of this onset speed for the many different types of motorcycles included in the dataset. Additional testing for damage onset, including different motorcycles and involving different portions of the target vehicle, would be beneficial and informational in this regard.

When utilizing the newly developed MBEs, it is important to carefully qualify the impact area as an axle, pillar, door, or fender. As mentioned, an axle impact should involve contact within six inches of the centerline of the axle. Once contact strays beyond this range, tire and wheel compliance reduces the automobile's stiffness, making the axle equation inappropriate.

It can often be difficult to determine how the struck portion of the automobile should be qualified, as the motorcycle will often engage surrounding portions of the vehicle. For instance, in Test 23 the motorcycle struck near the central portion of the right rear door of Hyundai, as shown in Figure 33. However, there was substantial damage to the adjacent C-pillar, and the rocker panel was deformed. While the analyst might first qualify this impact as a door strike, there seems to be an argument to qualify this as a stiffer pillar strike. Using the MBEs, the door model predicts an impact speed of 33.1 mph while the pillar model predicts 41.2 mph. The actual impact speed was 42.7 mph.

Difficulty in qualifying the impact area, in combination with typical automotive construction, may explain the scatter

FIGURE 33 Damage to the right door/pillar area of the Hyundai sustained during Test 23.

associated with the MB fender equations. While the average error for the MB fender equation is 0.0 mph, meaning the equation is just as likely to overestimate impact speed as underestimate impact speed, the SD is 7.0. The trailing portion of a typical fender will terminate at the junction with the vehicle's stiff A-pillar, near the middle of the fender will be a wheel assembly, and underlying the forward portion of the fender is the end of the bumper reinforcement (stiff) or often nothing (very soft). Considering this diverse structure, the struck portion of the fender could be either very stiff or very soft. If the impact is not qualified properly, it is difficult to predict an impact speed, or develop equations based on past testing. Again, this may explain why the fender results above are not as clean as the axle, pillar, or door data.

It is interesting to note that the Adamson, Modified Eubanks, and MBEs were best at predicting impact speeds despite not accounting for the weight of the motorcycle or automobile. The average weight of the motorcycles involved in the tests that the MBEs are based on is 476 lb with an SD of 120 lb, where the minimum weight is 200 lb and the maximum is 881 lb. With such a wide range of motorcycle weights, it seems that including the weight of the motorcycle in the model would be a benefit. However, an attempt to modify the MB model to include weight resulted in no improvement. In addition, the Wood and Searle models, which account for wheelbase reduction, maximum crush, and the weights of the vehicles, did not perform as well as the simpler Eubanks-based equations.

Where only maximum crush to the target automobile is known, Glynn's car-alone model performed well with respect to the subject Harley-Davidson dataset, and that model does account for the weights of both vehicles. The average error of the Glynn car-alone model was 1.7 mph and the SD was 8.8 mph. Though, one data point was substantially off, Test 22. In this test, the motorcycle struck the right rear axle of the Hyundai at a speed of 30.3 mph but only resulted in a total crush of 6.4 in. Glynn's model does account for hard and soft impact areas, but the axle is especially hard and this test demonstrates that the Glynn model is likely not suitable for analyzing axle strikes. However, upon removing that data point, the average error of the Glynn model increases to 4.3 mph while the SD improves substantially to 3.9 mph. When only automotive deformation is available for analysis, the Glynn car-alone model method can produce useful results, but the analyst should be cautious if an especially hard portion of the automobile is engaged, such as a wheel.

Whenever possible, the speed determination methods presented here should be bolstered by additional reconstruction methods and considered in the context of all available evidence (EDR data, tire marks, rider vault analysis, postimpact motion of the automobile, etc.). Utilizing multiple independent analytical methods improves confidence in the result and narrows the range of possible speeds.

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Appendix A - Test 3 Photographs

Appendix A - Test 5 Photographs

Appendix A - Test 8 Photographs

Appendix A - Test 11 Photographs

Appendix A - Test 22 Photographs

Appendix A - Test 23 Photographs

Appendix A - Test 24 Photographs

Appendix B - Source Data

Source	Motorcycle	MC wt (lb)	Automobile	Aut. wt (lb)	MC speed (mph)	L (in)	C (in)	Location
Adamson	1989-1993 Kawasaki KZ1000	631	1989 Ford Thunderbird	3590	30.0	3.3	3.5	Axle
Adamson	1989-1993 Kawasaki KZ1000	608	1989 Ford Thunderbird	3590	34.0	8.3	7.0	Bumper
Adamson	1989-1993 Kawasaki KZ1000	633	1989 Ford Thunderbird	3590	30.0	5.8	3.8	Bumper
Adamson	1989-1993 Kawasaki KZ1000	610	1989 Ford Thunderbird	3576	45.0	8.8	15.0	Bumper
Adamson	1989-1993 Kawasaki KZ1000	625	1989 Ford Thunderbird	3576	42.0	6.8	12.0	Door
Adamson	1989-1993 Kawasaki KZ1000	615	1989 Ford Thunderbird	3590	46.0	10.8	13.8	Fender
Adamson	1989-1993 Kawasaki KZ1000	620	1989 Ford Thunderbird	3590	39.0	7.6	10.5	Fender
Adamson	1989-1993 Kawasaki KZ1000	611	1989 Ford Thunderbird	3590	25.0	5.6	3.5	Fender
Adamson	1989-1993 Kawasaki KZ1000	595	1989 Ford Thunderbird	3576	41.0	7.5	5.8	Fender
Adamson	1989-1993 Kawasaki KZ1000	611	1989 Ford Thunderbird	3576	49.0	7.3	13.5	Fender
ARC-CSI 2008	1989 Yamaha FZR	401	1989 Honda Civic CRX	1947	22.0	7.0	2.0	Door
ARC-CSI 2008	1985 Yamaha Maxim	500	1984 Dodge B250	4582	35.0	7.0	7.0	Fender
ARC-CSI 2016	2011 H-D Road King FLHRC	794	2012 Volkswagen Passat	3360	31.9	5.0	6.2	Fender
ARC-CSI 2016	2011 H-D Heritage Softail FLSTC	748	2011 Ford Crown Victoria	4057	32.8	3.8	14.0	Fender
ARC-CSI 2016	2011 H-D Electra Glide FLHTCU	881	2012 Volkswagen Passat	3360	29.0	6.5	2.7	Pillar
CAARS 2004	1984 Kawasaki ZX750	500	1989 Chevrolet Cavalier Z24	2540	30.0	5.0	2.5	Axle
CAARS 2004	1990 Kawasaki ZX600	450	1982 Honda Prelude 2D	1710	50.0	9.0	11.0	Bumper
CAARS 2004	1976 Suzuki 750	525	1994 Plymouth Acclaim 4D	2565	52.0	9.0	11.0	Bumper
CAARS 2004	1981 Yamaha Virago	525	1989 Chevrolet Cavalier Z24	2540	34.0	7.0	1.0	Bumper
CAARS 2004	1991 Honda CBR600	525	1989 Chevrolet Cavalier Z24	2540	40.0	8.0	11.0	Door
CAARS 2004	1981 Suzuki GS650L	500	1989 Chevrolet Cavalier Z24	2540	46.0	9.5	14.0	Door
CAARS 2004	1982 Kawasaki KZ550	500	1992 Chevrolet Camaro	2900	51.5	10.5	19.5	Door
CAARS 2004	1978 Suzuki GS1000	575	1987 Chevrolet Blazer S10	3200	45.0	11.0	10.0	Door
CAARS 2004	1976 Honda CB550	500	1994 Plymouth Acclaim 4Dr	2565	45.0	11.0	11.0	Door
CAARS 2004	1989 Honda PC800	725	1982 Honda Prelude 2D	1710	32.0	8.0	17.5	Door
CAARS 2004	1980 Yamaha 750	600	1992 Chevrolet Camaro	2900	51.5	13.5	9.0	Fender
CAARS 2004	1986 Honda 450	400	1989 Chevrolet Cavalier Z24	2540	31.0	10.5	5.0	Pillar
CAARS 2004	1988 Honda CBR600F	450	1992 Chevrolet Camaro	2900	37.0	7.0	3.5	Pillar
CAARS 2004	1983 Yamaha XZ550	550	1992 Chevrolet Camaro	2900	46.0	8.5	10.0	Pillar
CAARS 2004	1980 Honda CM400T	475	1992 Chevrolet Camaro	2900	31.0	6.5	0.0	Pillar
CAARS 2004	1972 Honda 750	550	1987 Chevrolet Blazer S10	3200	52.5	12.5	7.5	Pillar

(Continued)

Source	Motorcycle	MC wt (lb)	Automobile	Aut. wt (lb)	MC speed (mph)	L (in)	C (in)	Location
CAARS 2004	1980 Honda 400	425	1987 Chevrolet Blazer S10	3200	40.0	10.5	4.5	Pillar
CAARS 2004	1980 Honda CX500	525	1994 Plymouth Acclaim 4D	2565	35.0	5.0	4.0	Pillar
CAARS 2004	1985 Honda VF500	525	1982 Honda Prelude 2D	1710	38.0	10.5	8.0	Pillar
CAARS 2004	1988 Honda CBR1000F	550	1994 Plymouth Acclaim 4D	2565	40.0	8.5	11.5	Pillar
CAARS 2004	1973 Honda CT360	450	1994 Plymouth Acclaim 4D	2565	66.0	12.0	17.5	Pillar
CAARS 2004	1975 Honda Goldwing	700	1982 Honda Prelude 2D	1710	31.0	6.0	5.0	Pillar
CAARS 2004	1978 Honda Goldwing	700	1982 Hondo Prelude 2D	1710	36.0	8.0	6.0	Pillar
CAARS 2009	2004 Kawasaki EX250-F	329	1989 Nissan Maxima	3049	54.5	12.0	6.0	Axle
CAARS 2009	1982 Yamaha XV920	443	1989 Honda Civic	2221	56.3	11.5	5.5	Axle
CAARS 2009	1982 Suzuki GS750	529	1992 Mercury Tracer	2402	59.8	12.0	10.0	Axle
CAARS 2009	1990 Honda PC800	615	1988 Honda Prelude	2662	32.9	5.5	2.0	Axle
CAARS 2009	Suzuki GS550E	379	1986 Honda Accord	2601	45.5	9.5	10.5	Door
CAARS 2009	1983 Honda VT750C	365	1986 Honda Accord	2601	35.9	9.5	6.5	Door
CAARS 2009	Suzuki LS6SO	352	1989 Nissan Maxima	3049	55.0	14.5	10.3	Door
CAARS 2009	1988 Honda CBR600F	413	1989 Nissan Maxima	3049	55.9	9.5	14.5	Door
CAARS 2009	1979 Suzuki GS550	419	1989 Honda Civic	2221	56.3	11.3	13.5	Door
CAARS 2009	1990 Kawasaki EX500A	415	1992 Mercury Tracer	2402	60.9	11.3	17.0	Door
CAARS 2009	1985 Honda CB650SC-F	465	1986 Mercedes 300E	3125	48.4	10.0	13.5	Door
CAARS 2009	1978 Honda Windjammer SS	636	1988 Honda Prelude	2662	29.8	6.8	7.0	Door
CAARS 2009	1984 Honda Goldwing 1200	670	1988 Honda Prelude	2642	58.8	9.5	20.0	Door
CAARS 2009	1983 Yamaha XJ750M	432	1986 Honda Accord	2601	40.1	8.0	3.8	Fender
CAARS 2009	1981 Kawasaki KZ440D	356	1986 Honda Accord	2601	37.9	5.0	1.5	Fender
CAARS 2009	1983 Honda CB550	398	1989 VW Golf	2114	45.5	8.3	4.5	Fender
CAARS 2009	1981 Kawasaki KZ440D	396	1989 VW Golf	2114	41.3	8.8	6.5	Fender
CAARS 2009	Kawasaki N/R	348	1989 Nissan Maxima	3049	54.0	9.0	15.0	Fender
CAARS 2009	Suzuki GS750	548	1992 Mercury Tracer	2402	59.3	9.0	11.5	Fender
CAARS 2009	Suzuki V5700GL	460	1986 Mercedes 300E	3125	44.3	14.5	7.0	Fender
CAARS 2009	1987 Suzuki GSXR750	422	1986 Mercedes 300E	3125	47.7	9.5	7.0	Fender
CAARS 2009	1982 Honda CM450C	391	1989 VW Golf	2114	47.0	8.0	12.5	Pillar
CAARS 2009	Yamaha Y1C5-?	444	1989 Honda Civic	2221	57.3	10.0	16.0	Pillar
CAARS 2009	1983 Suzuki GS1100ES	460	1986 Mercedes 300E	3125	49.1	9.0	21.0	Pillar
CAARS 2009	1978 Suzuki GS1000	491	1988 Honda Prelude	2642	60.3	13.0	14.5	Pillar
Hugemann		392			37.8	5.3	21.5	Door
Hugemann		360			31.5	6.5	14.8	Door
Hugemann		385			31.5	6.5	15.4	Door
Hugemann		345			44.1	8.5	24.4	Door
IATAI 2012	2003 Suzuki GSX-R1000 (USD)	405	2001 Buick Century	3302	36.1	5.0	4.5	Axle
IATAI 2012	1977 Honda CB400	382	2001 Buick Century	3302	17.8	5.3	0.0	Bumper
IATAI 2012	1981 Kawasaki CSR750	460	2001 Cadillac Deville	3940	33.7	13.3	0.0	Bumper
IATAI 2012	1986 Kawasaki EX250E	320	2001 Buick Century	3940	47.5	9.9	2.8	Bumper
IATAI 2012	2008 Kawasaki ZX600P (USD)	401	2001 Cadillac Deville	3302	44.9	6.9	1.0	Bumper
IATAI 2012	2008 Suzuki GSX-R600 (USD)	401	2001 Buick Century	3302	21.5	0.6	4.3	Door

(Continued)

Source	Motorcycle	MC wt (lb)	Automobile	Aut. wt (lb)	MC speed (mph)	L (in)	C (in)	Location
IATAI 2012	1996 Honda CBR600F3	402	2001 Cadillac Deville	3940	34.7	5.6	6.0	Pillar
IATAI 2012	2003 Suzuki VZ800	474	2001 Cadillac Deville	3940	35.7	11.0	4.0	Pillar
IATAI 2012	2008 Kawasaki ZX600J	397	2001 Cadillac Deville	3940	39.9	7.2	4.0	Pillar
IPTM 2011	1984 Yamaha FJ600L	360	2002 Saturn LW200 Wagon	3003	46.0	8.9	3.3	Axle
IPTM 2011	1986 Honda VT1100C Shadow	498	1988 Cadillac Deville	3282	54.0	13.0	5.0	Axle
IPTM 2011	1997 Kawasaki ZX600	446	1995 Lincoln Continental	3702	50.0	11.6	4.8	Axle
IPTM 2011	1986 Suzuki GS550ESG	436	1995 Lincoln Continental	3702	51.0	10.4	2.3	Axle
IPTM 2011	1985 Suzuki GS5S0ESG	372	1995 Lincoln Continental	3702	52.0	13.0	2.8	Axle
IPTM 2011	2001 Suzuki GSXR750K1	392	1994 Ford Escort	2300	55.4	9.3	6.5	Axle
IPTM 2011	1985 Honda VF700F Interceptor	484	1994 Ford Escort	2300	58.0	10.3	6.8	Axle
IPTM 2011	1982 Yamaha Maxim	474	1988 Cadillac Deville	3282	54.0	10.7	7.0	Fender
IPTM 2011	2002 Suzuki GSX600F	410	1996 Ford Explorer	3894	49.0	7 7	8.8	Fender
IPTM 2011	1987 Yamaha Virago XV535T	405	1995 Lincoln Continental	3702	50.0	11.3	6.5	Fender
IPTM 2011	1981 Honda CB900 Custom	586	2002 Saturn LW200 Wagon	3003	56.0	8.1	9.0	Fender
IPTM 2011	1980 Yamaha Special	354	1994 Ford Escort	2300	57.2	12.5	10.5	Fender
IPTM 2011	1980 Suzuki GN400	315	2002 Saturn LW200 Wagon	3003	46.0	9.6	3.5	Pillar
IPTM 2011	1982 Yamaha Virago XV920J	417	1988 Cadillac Deville	3282	51.0	13.8	8.0	Pillar
IPTM 2011	1981 Suzuki GN400X	290	1988 Cadillac Deville	3282	53.0	15.8	3.8	Pillar
Kasanicky	Suzuki 125	243	Mitsubishi		33.9	13.4	6.7	Door
Kasanicky	Kawasaki GPZ750	522			38.1	4.3	15.7	Door
Kasanicky	Aprilia Dual Sport	273	Toyota Corolla		20.7	3.1	4.0	Door
Kasanicky	Yamaha XS400	573			49.1	7.9	19.7	Door
Kasanicky	Honda CB400	551	Toyota Camry		61.7	9.1	21.7	Door
Severy	Honda CL-90	200	1964 Plymouth Fury	3900	30.0	9.2	5.0	Door
Severy	Honda CB-350	350	1964 Plymouth Fury	3900	30.0	8.5	6.5	Door
Severy	Honda CB-350	350	1964 Plymouth Fury	3900	20.0	4.7	3.4	Door
Severy	Honda CB-3S0	350	1964 Plymouth Fury	3900	30.0	9.5	5.5	Door
Severy	Honda CB-750	480	1964 Plymouth Fury	3900	30.0	9.3	4.2	Door
Severy	Honda CB 350	350	1964 Plymouth Fury	3900	40.0	13.0	11.5	Door
Severy	Honda CB-350	350	1964 Plymouth Fury	3900	30.0	9.5	6.3	Fender
WREX2016	1997 H-D Sportster 883	498	2006 Hyundai Sonata	3547	30.3	4.3	2.1	Axle
WREX2016	2013 H-D Softail Breakout	667	2006 Nissan Maxima	3449	43.0	11.3	18.7	Door
WREX2016	2013 H-D Dyna Street Bob	633	2006 Nissan Maxima	3449	36.9	12.8	8.6	Door
WREX2016	2012 H-D Dyna Low Rider	649	2005 Dodge Durango	4740	42.9	10.7	10.3	Door
WREX2016	2002 H-D Sportster 883	500	2006 Hyundai Sonata	3547	42.7	8.8	7.1	Pillar
WREX2016	2003 H-D Sportster 883	483	2006 Hyundai Sonata	3547	35.5	8.9	4.2	Pillar