Symposium on Traffic Safety

featuring

Special Problems in Crash Reconstruction
Symposium on Impaired Driving Enforcement

May 21-24, 2018
Orlando, Florida

Motorcycles: Myths, Methodologies and Momentum

Detective Ken Strohmeyer
Scottsdale (Arizona) Police Department
Motorcycles: Myths, Methodologies and Momentum
So, you want to ride a Motorcycle?

- 29 times more likely to die than a passenger car occupant per vehicle mile driven
- 40% of the time it is a single vehicle crash
- 91% of all fatalities are male
- 68% of female fatalities are passengers
- 35% of all fatalities are over 50 years of age, 29% under 29 years of age
- Major Roads (main city streets) account for 62% of fatalities (12% Interstate)
- 48% of fatalities happen on the weekend
# Occupant Fatality Rates by Vehicle Type, 2006 and 2015

<table>
<thead>
<tr>
<th>Fatality Rate</th>
<th>Motorcycle</th>
<th>Light Trucks</th>
<th>Passenger Car</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2006</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Per 100k registered</td>
<td>72.42</td>
<td>13.01</td>
<td>13.08</td>
</tr>
<tr>
<td>Per 100m miles traveled</td>
<td>40.14</td>
<td>1.1</td>
<td>1.11</td>
</tr>
<tr>
<td><strong>2015</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Per 100k registered</td>
<td>57.85</td>
<td>7.7</td>
<td>9.48</td>
</tr>
<tr>
<td>Per 100m miles traveled</td>
<td>25.38</td>
<td>0.72</td>
<td>0.89</td>
</tr>
<tr>
<td><strong>Percent Change</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Per 100k registered</td>
<td>-20.10%</td>
<td>-40.80%</td>
<td>-27.50%</td>
</tr>
<tr>
<td>Per 100m miles traveled</td>
<td>-36.8%</td>
<td>-34.5%</td>
<td>-19.8%</td>
</tr>
</tbody>
</table>

Source: U.S. Dept. of Transportation and National Highway Traffic Safety Administration

Motorcycles: Myths, Methodologies and Momentum
Wear a helmet or not, that is the question…

- 37% effective in preventing deaths
- 67% effective in preventing serious brain injury

Can we say a helmet will prevent fatalities? What is the likelihood of the death if the rider was wearing a helmet?
Myths: What have you heard?

Motorcycles  Myths, Methodologies and Momentum
What have you been told?

- S curved skid marks are a sign of rear wheel braking
- Straight skids are a sign the front brake was used.
What have you been told?

▪ “a single long straight skid mark may well be caused by a rear wheel skid generated while the front brake was used (particularly if the motorcycle was still traveling at some speed at the end of the mark), but one can NOT be confident to the level of 'more likely than not', let alone ‘beyond a reasonable doubt’ that this is true. The 'lazy-S' shape clearly indicates a rear brake skid mark, but without additional supporting information does not indicate ‘to a reasonable degree of certainty’ that the front brake was not used. Similarly, a serpentine mark can be generated with front brake use, and is dependent on the operator’s 'body language'. Without testing the actual tires in use on particular the bike, or in some cases examining the tires themselves prior to their being driven on much, it may not be possible to confidently identify which tire made a particular short mark, or the vehicle's braking condition. With representative exemplar marks made under known conditions (rear only and front with rear) and using the actual tires in use on the accident unit, it would probably be possible to identify the braking condition at the time of the accident.”


▪ “it is difficult to determine which brakes the rider used from only the observation of braking marks.”

What does that mean?

▪ Underestimating pre-crash braking
  ▪ Standard Brakes (no ABS or Linking)
    ▪ Rear: 0.37 ± 0.6
    ▪ Front: 0.60 ± 0.16
    ▪ Both: 0.74 ± 0.15

## Average Deceleration (g)

<table>
<thead>
<tr>
<th></th>
<th>Standard</th>
<th>Integrated</th>
<th>ABS</th>
<th>Integrated ABS</th>
<th>Linked</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rear</td>
<td>51%</td>
<td>70%</td>
<td>49%</td>
<td>121%</td>
<td>75%</td>
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<tr>
<td>Front</td>
<td>78%</td>
<td>89%</td>
<td>108%</td>
<td>111%</td>
<td>104%</td>
</tr>
<tr>
<td>Both</td>
<td>85%</td>
<td>107%</td>
<td>113%</td>
<td>119%</td>
<td>112%</td>
</tr>
</tbody>
</table>

Roadway Automobile $\mu = 0.83$

### Average Deceleration (g)

<table>
<thead>
<tr>
<th></th>
<th>Standard</th>
<th>Integrated</th>
<th>ABS</th>
<th>Integrated ABS</th>
<th>Linked</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rear</td>
<td>0.42</td>
<td>0.58</td>
<td>0.40</td>
<td>1.00</td>
<td>0.62</td>
</tr>
<tr>
<td>Front</td>
<td>0.60</td>
<td>0.73</td>
<td>0.89</td>
<td>0.92</td>
<td>0.86</td>
</tr>
<tr>
<td>Both</td>
<td>0.70</td>
<td>0.88</td>
<td>0.93</td>
<td>0.98</td>
<td>0.92</td>
</tr>
</tbody>
</table>

Roadway Automobile $\mu = 0.83$

---

What have you Heard?

▪ Drag Factor
  ▪ At least 15 different studies have been conducted on a motorcycle sliding on pavement. (published works)
  ▪ Tests were done with all types of “clad” and “unclad” motorcycles, in some the type was specified and in others it was not.
  ▪ Different test modalities
  ▪ Small data sets
What have you Heard?

▪ Drag Factor

▪ Bartlett, et al (2007) summarized 162 IPTM tests using 99 different motorcycles and the mean drag factor was 0.521 with a standard deviation of 0.140.

▪ They then combined this with other research to build a database of 386 tests. The mean was 0.480 with a standard deviation of 0.134.

▪ Separating out the data for fully clad motorcycle, the mean was 0.37 with a standard deviation of 0.08
What have you Heard?

▪ Drag Factor
  ▪ Day and Smith (84) tested unclad motorcycles and determined a range of 0.45 – 0.58
  ▪ Peck, Focha, Gloekler (2014) tested motorcycles with plastic sliders the results were an average of 0.45 and a standard deviation of 0.09 which is more consistent with unclad motorcycles.
  ▪ Interesting to note that for the slider tests all had riders.


Motorcycles: Myths, Methodologies and Momentum
386 Tests

Motorcycles: Myths, Methodologies and Momentum
Motorcycles: Myths, Methodologies and Momentum
Clad Motorcycles

Motorcycles: Myths, Methodologies and Momentum
Motorcycles: Myths, Methodologies and Momentum
## Summary

<table>
<thead>
<tr>
<th></th>
<th>Avg</th>
<th>Std Dev</th>
<th>Range: 2SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>386 Tests</td>
<td>0.519</td>
<td>0.140</td>
<td>0.239 to 0.799</td>
</tr>
<tr>
<td>Day and Smith</td>
<td>0.514</td>
<td>0.037</td>
<td>0.440 to 0.589</td>
</tr>
<tr>
<td>Clad Motorcycles</td>
<td>0.370</td>
<td>0.079</td>
<td>0.212 to 0.528</td>
</tr>
<tr>
<td>Sliders &amp; Riders</td>
<td>0.451</td>
<td>0.090</td>
<td>0.271 to 0.630</td>
</tr>
</tbody>
</table>
Methodologies: How Fast was he going?

Motorcycles  Myths, Methodologies and Momentum
Slide to Stop

\[ S = \sqrt{30df} \]

- Works well for:
  - Single vehicle crashes with no impacts
  - Motorcycle down and misses the other vehicle
  - Parts separated from the motorcycle in the crash

Motorcycles: Myths, Methodologies and Momentum
Slide to Stop

\[ S = \sqrt{30df} \]

• Issues:
  - Determining total distance
  - Tumbling, sliding, multiple surfaces
  - What drag factor to use
Motorcycles: Myths, Methodologies and Momentum
Slide to Stop

The motorcycle left tire marks leading up to the point where it went down and the motorcycle and rider went in different directions. The riders first mark on the roadway appears to be a helmet scuff approximately 66 feet from the last tire mark. The motorcycle's first mark after the last tire mark is a gouge approximately 17 feet away. The motorcycle left marks consistent with the crash bars sliding on the roadway. The rear crash bar on the left side was heavily worn. The motorcycle went approximately 596 feet before colliding with the barrier wall on the west side of the freeway. It went another 142 feet along the wall before coming to rest on its right side facing southeast.

Based on published data, metal sliding on asphalt generated a drag factor of 0.45 (f=0.45). The total distance for the motorcycle is 738 feet. Using the basic speed formula, the motorcycle was traveling approximately 99.81 mph. This is a minimum speed and does not take into consideration the energy lost in the impact with the wall.

\[ \sqrt{30df} = \sqrt{30 \times 738 \times 0.45} = \sqrt{9963} = 99.81 \text{ mph} \]
The rider traveled 397 feet from first mark to last mark. Data shows a tumbling body generates a drag factor of 0.60 to 1.0 depending on the type of clothing and how much tumbling versus sliding. In this case, a drag factor of 0.80 ($f=0.80$) was used. The basic speed formula produces a speed of 97.61 mph.

\[
\sqrt{30df} = \sqrt{30 \times 397 \times 0.80} = \sqrt{9528} = 97.61 \text{ mph}
\]
The speed at the start of the tire marks is slightly more complicated to determine. It is unsure how much of a drag factor is generated during the time the tire is marking. Turning generates approximately 20% braking efficiency while front wheel only braking generates approximately 60% braking efficiency for a motorcycle. This will establish a range for the drag factor: 0.14 (turning) to 0.42 (front wheel braking) assuming a coefficient of friction for the roadway of 0.70. The tire marks prior to the motorcycle going down were 352 feet. The combined speed formula produces a speed at the beginning of the tire marks for the motorcycle of 106.95 mph to 119.98 mph. This assumes no throttle was being applied.

\[
\sqrt{S_o^2 + 30df} = \sqrt{99.81^2 + (30 \times 352 \times 0.14)} = \sqrt{11440.4} = 106.95 \text{ mph}
\]

\[
\sqrt{S_o^2 + 30df} = \sqrt{99.81^2 + (30 \times 397 \times 0.42)} = \sqrt{14397.2} = 119.98 \text{ mph}
\]
Searle

\[ S = \sqrt{\frac{30df}{\cos \theta + f \sin \theta}} \]

\[ S_{\text{Min}} = \frac{\sqrt{30df}}{1 + f^2} \]

\[ S_{\text{Max}} = \sqrt{30df} \]

- Rider separates from the motorcycle:
  - How much interaction with the motorcycle?
  - Launch angle?
  - Passenger?

Motorcycles: Myths, Methodologies and Momentum
Speed from Gear

- Max speed for that gear:
  - Could the motorcycle be going that fast?
  - What is the fastest speed attainable for that gear?
  - Stuck RPM needle
**Speed from Gear**

\[ S_{road,max} = \frac{S_{rpm,max}}{r_{pr} \times r_{fr} \times r_{i}} \times c_{rear} \times \frac{60}{5280} \]

- \( S_{road,max} \) = Upper limit of speed in the gear in question
- \( S_{rpm,max} \) = Maximum engine speed in RPMs
- \( r_{pr} \) = Primary reduction ratio
- \( r_{fr} \) = Final Reduction ratio
- \( r_{i} \) = Gear ratio of specific gear
- \( c_{rear} = \frac{2\pi r_{rear}}{12} \) = Distance rolled per revolution of the rear tire given the radius of the rear tire (\( r_{rear} \))

---

Motorcycles: Myths, Methodologies and Momentum
Speed from Gear

Toyota Tundra pulls out in front of a Suzuki SV650s. The rider of the M/C somehow has the motorcycle sideways at impact with the truck’s front axle.
What does that mean?
<table>
<thead>
<tr>
<th>Time (msec)</th>
<th>Lateral Delta-V, Airbag ECU Sensor (MPH [km/h])</th>
<th>Lateral Delta-V, B-Pillar Sensor (MPH [km/h])</th>
<th>Lateral Delta-V, C-Pillar Sensor (MPH [km/h])</th>
</tr>
</thead>
<tbody>
<tr>
<td>-24</td>
<td>0.1 [0.2]</td>
<td>0.0 [0.0]</td>
<td>-0.1 [-0.2]</td>
</tr>
<tr>
<td>-18</td>
<td>0.2 [0.3]</td>
<td>0.0 [0.0]</td>
<td>-0.1 [-0.2]</td>
</tr>
<tr>
<td>-12</td>
<td>0.3 [0.5]</td>
<td>0.0 [0.0]</td>
<td>-0.1 [-0.2]</td>
</tr>
<tr>
<td>-6</td>
<td>0.4 [0.7]</td>
<td>0.0 [0.0]</td>
<td>-0.1 [-0.2]</td>
</tr>
<tr>
<td>0</td>
<td>0.8 [1.3]</td>
<td>-0.4 [-0.7]</td>
<td>-0.3 [-0.5]</td>
</tr>
<tr>
<td>6</td>
<td>1.4 [2.3]</td>
<td>-0.4 [-0.7]</td>
<td>-0.1 [-0.2]</td>
</tr>
<tr>
<td>12</td>
<td>2.9 [4.6]</td>
<td>0.0 [0.0]</td>
<td>0.3 [0.5]</td>
</tr>
<tr>
<td>18</td>
<td>4.0 [6.5]</td>
<td>1.3 [2.1]</td>
<td>0.4 [0.7]</td>
</tr>
<tr>
<td>24</td>
<td>5.5 [8.8]</td>
<td>2.6 [4.2]</td>
<td>0.4 [0.7]</td>
</tr>
<tr>
<td>30</td>
<td>6.7 [10.8]</td>
<td>3.4 [5.5]</td>
<td>0.7 [1.2]</td>
</tr>
<tr>
<td>36</td>
<td>7.9 [12.8]</td>
<td>4.7 [7.6]</td>
<td>1.3 [2.1]</td>
</tr>
<tr>
<td>42</td>
<td>8.5 [13.6]</td>
<td>5.6 [9.0]</td>
<td>2.1 [3.3]</td>
</tr>
<tr>
<td>48</td>
<td>8.7 [13.9]</td>
<td>5.2 [8.3]</td>
<td>2.4 [3.8]</td>
</tr>
<tr>
<td>54</td>
<td>8.9 [14.3]</td>
<td>4.3 [6.9]</td>
<td>2.1 [3.3]</td>
</tr>
</tbody>
</table>
Can you do that?

- The truck registered a lateral $\Delta v$ of 8.9 mph. The truck was basically stopped in the lateral direction so all of the energy to cause that would have come from the motorcycle.

- The motorcycle $\Delta v$ can be determined by the following formula:

$$\Delta V_2 = \frac{W_1 \Delta V_1}{W_2}$$

\[
\begin{align*}
W_1 &= 5295 \text{ lb} \\
W_2 &= 524 \text{ lb} \\
\Delta V_1 &= 8.9 \text{ mph}
\end{align*}
\]

$$\Delta V_2 = \frac{5295 \times 8.9}{524} = 89.93 \text{ mph}$$
Can you do that?

- This would be a minimum speed which ignores restitution and other ground forces.
- The motorcycle was found to be in third gear
  - $r_{pr} = 2.088$
  - $r_{fr} = 3.000$
  - $r_i = 1.380$
  - Gear Final drive = 8.644
  - Max power 9000 rpm
  - $r_{rear} = 12.25$ inches
Can you do that?

\[ S_{road,max} = \frac{S_{rpm,max}}{r_{pr} * r_{fr} * r_i} * c_{rear} * \frac{60}{5280} \]

\[ c_{rear} = \frac{2\pi r_{rear}}{12} = \frac{2 * 3.14 * 12.25}{12} = 6.414 \text{ feet} \]

\[ S_{road,max} = \frac{9000}{2.088 * 3.000 * 1.380} * 6.414 * \frac{60}{5280} \]

\[ S_{road,max} = 1041.14 * 6.414 * 0.01136 = 75.88 \text{ mph} \]
Can you do that?

$$\Delta V_2 = \frac{W_1 \Delta V_1}{W_2} = \frac{5295 \times 8.9}{524} = 89.93 \text{ mph}$$

$$S_{\text{road, max}} = 1041.14 \times 6.414 \times 0.01136 = 75.88 \text{ mph}$$
Can you do that?

NO!
Can you do that?

The speed from gear formulas give us a reason to look elsewhere:

After a discussion with Rick Ruth, this does not work because of the way the EDR records data in this type of crash.
Energy Methods

- Wheelbase Reduction
- Wheelbase Reduction + maximum car crush
- CRASH style analysis (force balancing)
Momentum: Shouldn’t this be under myths?

Motorcycles Myths, Methodologies and Momentum
Motorcycle Speed Estimates Using Conservation of Linear and Rotational Momentum

Bruce F. McNally, ACTAR
McNally and Associates Accident Reconstruction Services, LLC

Wade Bartlett, PE, ACTAR
Mechanical Forensics Engineering Services, LLP

Presented at the 20th Annual Special Problems in Traffic Crash Reconstruction at the Institute of Police Technology and Management, University of North Florida, Jacksonville, Florida, April 15-19, 2002
Momentum

- Fricke and Riley indicate in Topic 874 of the Traffic Accident Investigation Manual that “occasionally a momentum analysis is attempted” and that this technique “rarely... works well” in accurately estimating the speed of the motorcycle.

- In 1990, Brown and Obenski write that a momentum analysis “can sometimes be used in motorcycle accidents,” and give a graphical example of a momentum vector diagram of a motorcycle/automobile collision.

- In 1994, Obenski further clarifies this position by stating “Generally it is tricky to use momentum analysis in accidents between vehicles with a big weight difference,” but gives the same graphical example as in his previous work. Obenski specifically cautions against using a momentum analysis where the automobile has been moved very little after impact with the motorcycle.

- In 1990, Niederer wrote about techniques that may be used to reconstruct motorcycle/vehicle collisions, with the emphasis of the paper on the use of conservation of linear and angular momentum. Niederer specifically cautions that “due to the often unfavourable mass ratio an accurate reconstruction may be impeded,” but concludes that when used cautiously, the use of momentum and other available information “represents a powerful tool for motorcycle-vehicle collision reconstruction.”
Momentum

- Redirection of both Vehicle’s Center of Mass
- Uncontrolled rest of both vehicles
- Momentum not more than 10 to 1 difference
Momentum Case #1

- Vehicle #1 was stopped on Scottsdale Road at Jomax Road in the n/b left turn lane. Vehicle #2 was traveling s/b through a green signal in the #1 lane of Scottsdale Road at Jomax Road. Vehicle #1 started to turn w/b onto Jomax and stopped in the #1 s/b lane of Scottsdale Road. The front of Vehicle #2 collided with the front of Vehicle #1.
Case #1

Motorcycles: Myths, Methodologies and Momentum
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Momentum Case #1

Motorcycles: Myths, Methodologies and Momentum
Momentum Case #1

- Audi A7: $d=9\text{ft}$, $f=0.75$, $SD=0.05$, $S_2=0\text{ mph}$, $W=4408\text{ lbs}$
- Honda ST1300: $d=40\text{ft}$, $f=0.37$, $SD=0.08$, $W=845\text{ lbs}$
- Rider: $d=148\text{ ft}$, $f_{\text{Searle}}=0.66$, $W=290\text{ lbs}$
Motorcycles: Myths, Methodologies and Momentum

**Momentum Case #1**

<table>
<thead>
<tr>
<th></th>
<th>Audi</th>
<th>Avg</th>
<th>Std Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>distance</td>
<td>9</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>drag factor</td>
<td>0.7</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>weight</td>
<td>4408</td>
<td>200</td>
<td></td>
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</tbody>
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<table>
<thead>
<tr>
<th></th>
<th>Honda</th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>distance</td>
<td>40</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>drag factor</td>
<td>0.37</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>weight</td>
<td>845</td>
<td>38</td>
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<table>
<thead>
<tr>
<th></th>
<th>Rider</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>distance</td>
<td>148</td>
<td>2.96</td>
<td></td>
</tr>
<tr>
<td>drag factor</td>
<td>Searle</td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td>weight</td>
<td>290</td>
<td>13</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Audi</th>
<th>Honda</th>
<th>Rider</th>
<th>Momentum</th>
</tr>
</thead>
<tbody>
<tr>
<td>d</td>
<td>f</td>
<td>Sa</td>
<td>W</td>
</tr>
<tr>
<td>8.854763</td>
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<td>12.98</td>
<td>4384.068</td>
</tr>
<tr>
<td>8.819332</td>
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<td>13.85133</td>
<td>4331.538</td>
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</table>
Motorcycles: Myths, Methodologies and Momentum
<table>
<thead>
<tr>
<th></th>
<th>Time</th>
<th>Distance</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>2.498213</td>
<td>332.5886</td>
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</tr>
<tr>
<td>Range</td>
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<td>2.52</td>
<td></td>
</tr>
<tr>
<td>Distance Avg</td>
<td>2.486576</td>
<td>322.6992</td>
<td>88.52423</td>
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<tr>
<td>Std Dev</td>
<td>315</td>
<td>15.75</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.438465</td>
<td>337.8767</td>
<td>94.5165</td>
</tr>
<tr>
<td></td>
<td>2.494786</td>
<td>320.4267</td>
<td>87.61158</td>
</tr>
<tr>
<td></td>
<td>2.502809</td>
<td>315.0139</td>
<td>85.85549</td>
</tr>
</tbody>
</table>

Average: 86.79066
Std Dev: 4.466936
Range 2d: 77.85678 to 95.72453
Motorcycles: Myths, Methodologies and Momentum
Momentum Case #2

Motorcycles: Myths, Methodologies and Momentum
Motorcycles: Myths, Methodologies and Momentum
Motorcycles: Myths, Methodologies and Momentum
This Collision involved two vehicles: #1 was a blue 2008 Pontiac G6. #2 was a white 2012 Honda ST1300 Police Motorcycle.

Damage to both units along with roadway evidence placed the area of impact in the eastbound #1 lane of Chandler Blvd. The motorcycle was believed to have been stopped on Chandler Blvd at the intersection of Pennington Dr. when the G6 struck it from behind.
### Momentum Case #2

#### Pre-Crash Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>-5 sec</th>
<th>-4 sec</th>
<th>-3 sec</th>
<th>-2 sec</th>
<th>-1 sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Speed (MPH)</td>
<td>48</td>
<td>51</td>
<td>52</td>
<td>55</td>
<td>57</td>
</tr>
<tr>
<td>Engine Speed (RPM)</td>
<td>3008</td>
<td>3072</td>
<td>3136</td>
<td>3200</td>
<td>3272</td>
</tr>
<tr>
<td>Percent Throttle</td>
<td>70</td>
<td>71</td>
<td>73</td>
<td>74</td>
<td>35</td>
</tr>
<tr>
<td>Brake Switch Circuit State</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
<td>OFF</td>
</tr>
<tr>
<td>Accelerator Pedal Position (percent)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Antilock Brake System Active (If Equipped)</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Lateral Acceleration (feet/s²) (If Equipped)</td>
<td>Invalid</td>
<td>Invalid</td>
<td>Invalid</td>
<td>Invalid</td>
<td>Invalid</td>
</tr>
<tr>
<td>Yaw Rate (degrees per second) (If Equipped)</td>
<td>Invalid</td>
<td>Invalid</td>
<td>Invalid</td>
<td>Invalid</td>
<td>Invalid</td>
</tr>
</tbody>
</table>
### Momentum Case #2

#### Motorcycles: Myths, Methodologies and Momentum

<table>
<thead>
<tr>
<th>Time (milliseconds)</th>
<th>-70</th>
<th>-60</th>
<th>-50</th>
<th>-40</th>
<th>-30</th>
<th>-20</th>
<th>-10</th>
<th>0</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
<th>70</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDM Longitudinal Axis Recorded Velocity Change (MPH)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>-1.36</td>
<td>-2.03</td>
<td>-4.07</td>
<td>-6.10</td>
<td>-9.49</td>
<td>-12.20</td>
<td>-13.55</td>
<td>-13.55</td>
<td>-14.23</td>
<td>-13.55</td>
<td>0.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time (milliseconds)</th>
<th>80</th>
<th>90</th>
<th>100</th>
<th>110</th>
<th>120</th>
<th>130</th>
<th>140</th>
<th>150</th>
<th>160</th>
<th>170</th>
<th>180</th>
<th>190</th>
<th>200</th>
<th>210</th>
<th>220</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDM Longitudinal Axis Recorded Velocity Change (MPH)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>
Momentum Case #2

\[ S_{G6} = \frac{W_{G6}S_3 + W_{MC}S_4}{W_{G6}} \]

Weight of vehicle #1:  
- Base Weight – 3305 lbs. (Edmonds.com)
- D#1’s Weight - 145 lbs. (AZ/DL)
- Total Weight - 3450 lbs.

Weight of Vehicle #2:  
- Base Weight - 730 lbs. (NADA)
- Equipment - 200 lbs.
- D#2’s Weight - 200 lbs.
- Total Weight - 930 lbs.
Momentum Case #2

\[ S_{G6} = \frac{W_{G6}S_3 + W_{MC}S_4}{W_{G6}} \]

\[ W_{G6} = 3450 \text{ lbs} \]
\[ W_{MC} = 1130 \text{ lbs} \]
\[ S_3 = S_{CDR} \]
\[ \Delta V = 57 - 14 = 43 \text{ mph} \]
\[ S_4 = 53.93 \]

\[ S_{G6} = \frac{3450 \times 43 + (1130 \times 53.93)}{3450} \]
\[ S_{G6} = 60.35 \text{ mph} \]
Momentum Case #2

\[
S_{G6} = \frac{W_{G6}S_3 + W_{MC}S_4}{W_{G6}}
\]

\[
W_{G6} = 3450 \text{ lbs}
\]
\[
W_{MC} = 930 \text{ lbs}
\]
\[
S_3 = S_{CDR} \quad \Delta V = 57 - 14 = 43 \text{ mph}
\]
\[
S_4 = 53.93
\]

\[
S_{G6} = \frac{3450 * 43 + (930 * 53.93)}{3450}
\]
\[
S_{G6} = \frac{197640}{3450}
\]
\[
S_{G6} = 57.28 \text{ mph}
\]
Momentum Case #2

CDR Speed Range = 55 to 59 mph

\[ S_{G6} = 57.28 \text{ mph} \]
Special Thanks to:

Nathan Rose

“Motorcycle Crash Reconstruction”
By Nathan Rose

Forthcoming Book from the Society of Automotive Engineers
Due out late 2018